VIRGINIA DEQ STORMWATER
DESIGN SPECIFICATION No. 1

ROOFTOP (IMPERVIOUS SURFACE) DISCONNECTION

VERSION 1.9
March 1, 2011

SECTION 1: DESCRIPTION

This strategy involves managing runoff close to its source by intercepting, infiltrating, filtering, treating or reusing it as it moves from the impervious surface to the drainage system. Two kinds of disconnection are allowed: (1) simple disconnection, whereby rooftops and/or on-lot residential impervious surfaces are directed to pervious areas, and (2) disconnection leading to an alternative runoff reduction practice(s) adjacent to the roof (**Figure 1.1**). Alternative practices can use less space than simple disconnection and can enhance runoff reduction rates. Applicable practices include:

- Soil compost amended filter path [Stormwater (SW) Design Spec 4]
- Infiltration by micro-infiltration practice (dry wells or french drains, SW Design Spec 8)
- Filtration by rain gardens or micro-bioretention (SW Design Spec 9)
- Storage and reuse with a cistern or other vessel (rainwater harvesting) (SW Design Spec 6)
- Storage and release in a stormwater planter. (SW Design Spec 9, Appendix A)

Larger scale (e.g., commercial) applications that utilize disconnection and/or sheetflow for runoff reduction credit should consult Stormwater Design Specification 2: Filter Strips.

Figure 1.1 portrays various rooftop disconnection and alternative runoff reduction options.

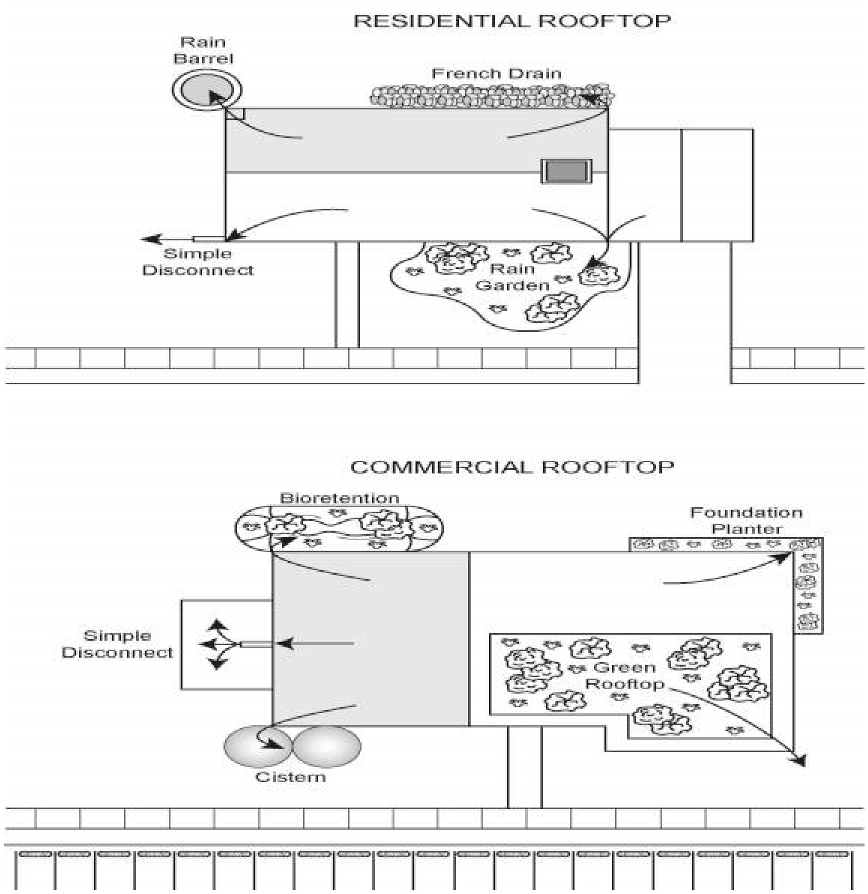


Figure 1.1 Roof Disconnection with Alternative Runoff Reduction Practices

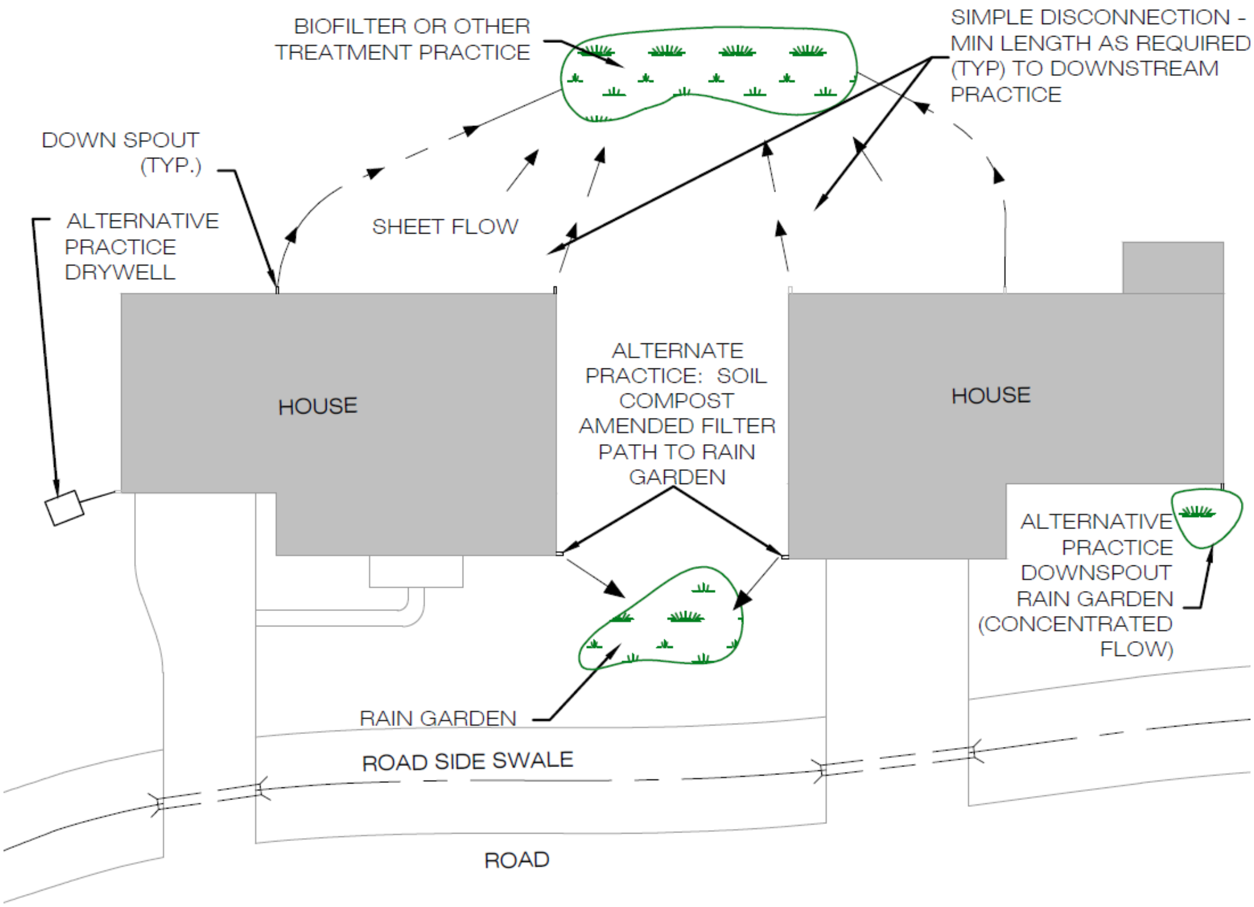


Figure 1.2. Residential Rooftop Treatment – Plan View:
a) Simple Disconnection;
b) Simple Disconnection to downstream Raingarden;
c) Disconnection – Alternative Practice: Raingarden;
d) Disconnection – Alternative Practice: Compost Amended Flow Path to downstream Raingarden;
e) Disconnection – Alternative Practice: Dry Well (micro-infiltration);

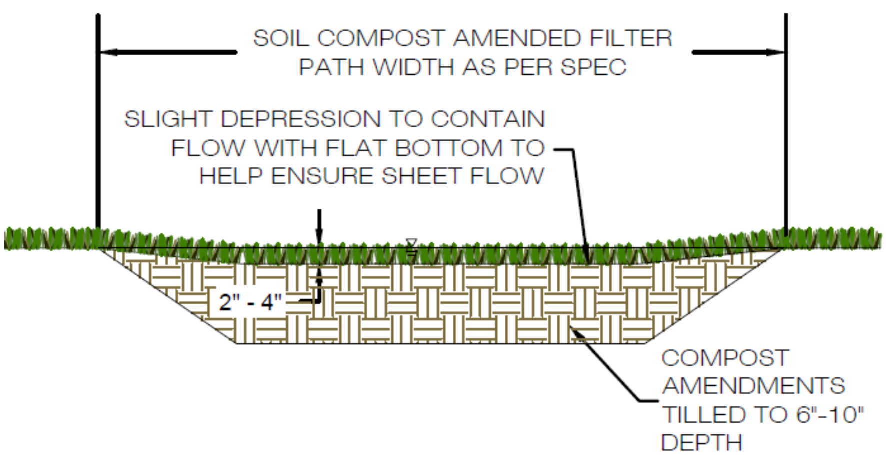


Figure 1.3. Disconnection: Soil Compost Amended Filter Path

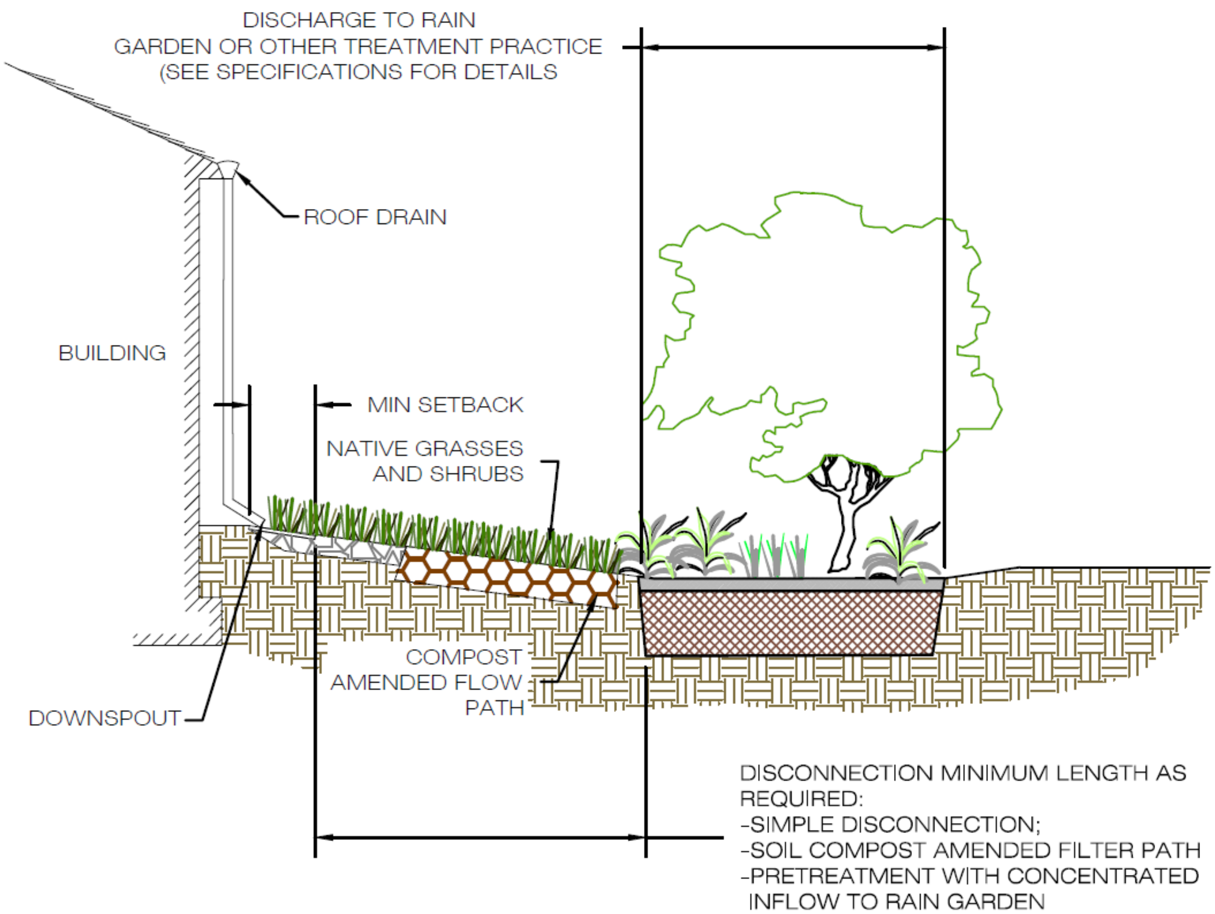


Figure 1.4. Residential Rooftop Disconnection – Section View:
a) Simple Disconnection to downstream Raingarden
b) Disconnection – Alternative Practice: Compost Amended Flow Path to downstream Raingarden

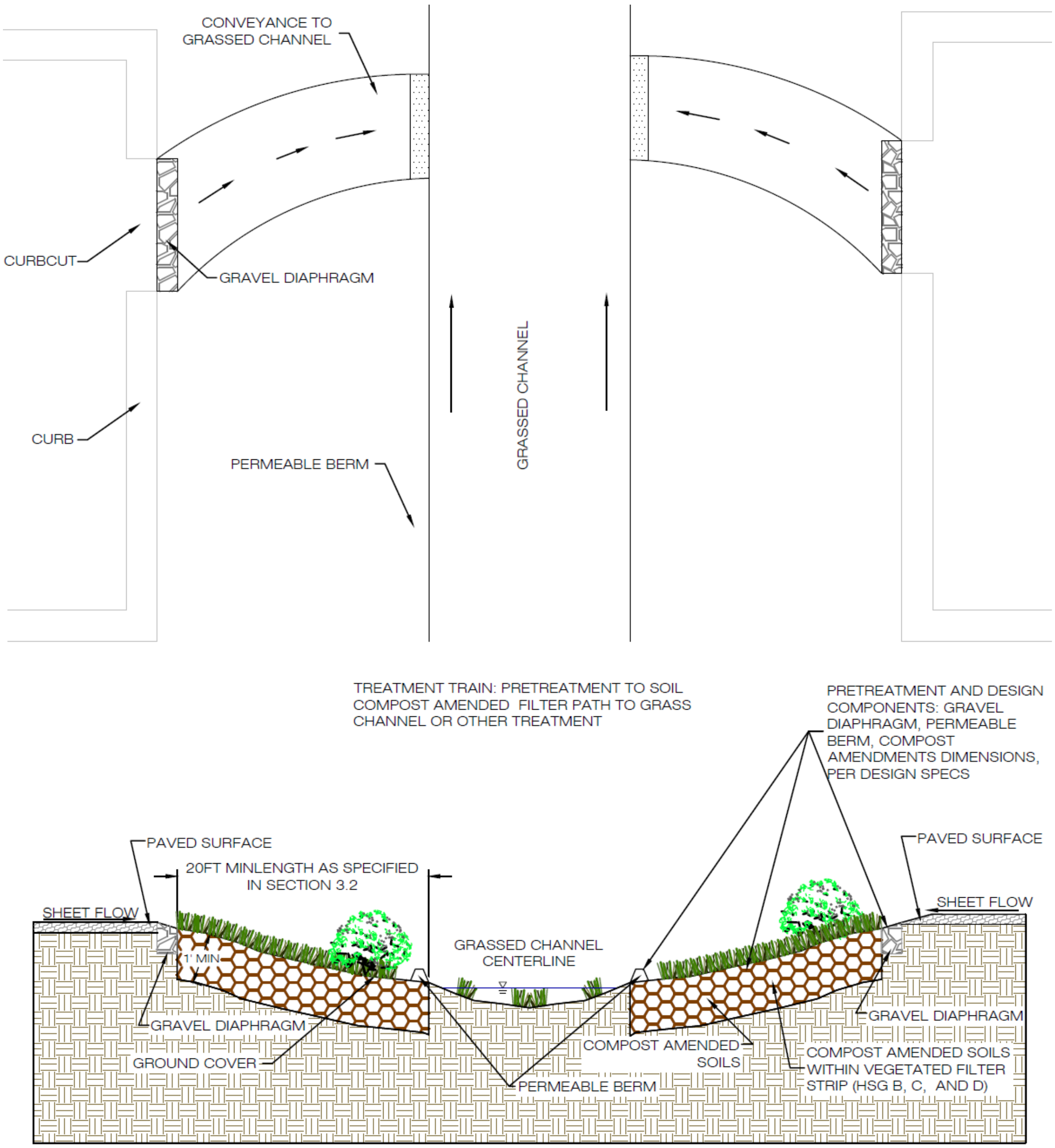


Figure 1.5. Amended Filter Path to Downstream Grass Channel (or other treatment)

SECTION 2: PERFORMANCE

With proper design and maintenance, the simple rooftop disconnection options can provide relatively high runoff reduction rates, although they are not credited with nutrient removal (**Table 1.1**). If an alternative runoff reduction practice is employed to achieve rooftop disconnection, the higher runoff reduction rate for that practice can be used for the contributing drainage area of the rooftop. In some cases, the designer may choose to use one of the alternative practices noted above in order to provide both runoff reduction and nutrient removal, regardless of space constraints.

The runoff reduction achieved by rooftop disconnections can help reduce the overall channel protection and flood control volume for the site. Designers can use the Runoff Reduction Method (RRM) spreadsheet to calculate a curve number adjustment for each design storm for the contributing drainage area, based on the degree of runoff reduction achieved.

Table 1.1. Summary of Stormwater Functions Provided by Rooftop Disconnection [1]

FUNCTION PROVIDED BY SIMPLE ROOFTOP DISCONNECTION	HSG SOILS A and B	HSG SOILS C and D
Annual Runoff Volume Reduction (RR)	50%	25%
Total Phosphorus (TP) EMC Reduction by BMP Treatment Process	0	0
Total Phosphorus (TP) Mass Load Removal	50%	25%
Total Nitrogen (TN) EMC Reduction by BMP Treatment Process	0	0
Total Nitrogen (TN) Mass Load Removal	50%	25%
Channel & Flood Protection	**Partial:** Designers can use the RRM spreadsheet to adjust curve number for each design storm for the contributing drainage area (CDA), based on annual runoff reduction achieved	
NOTE: Stormwater functions of disconnection can be boosted if an acceptable alternative runoff reduction practice is employed. Acceptable practices and their associated runoff reduction rates are listed below. Designers should consult the applicable specification number for design standards.		
Alternative Practice	**Specification No.**	**Runoff Reduction Rate**
Soil compost-amended filter path	4	50%
Dry well or french drain #1 (Micro-infiltration #1)	8	50%
Dry well or french drain #2 (Micro-infiltration #2)	8	90%
Rain garden #1, front yard bioretention (Micro-bioretention #1)	9	40%
Rain garden #2, front yard bioretention (Micro-bioretention #2)	9	80%
Rainwater harvesting	6	Defined by user
Stormwater Planter (Urban Bioretention)	9 (Appendix A)	40%
[1] CWP and CSN (2008), CWP (2007)		

SECTION 3: DESIGN TABLES AND CRITERIA

3.1. Simple Rooftop Disconnection

Table 1.2 provides the primary design criteria for simple rooftop disconnection.

- Simple disconnection is generally not advisable for residential lots less than 6,000 square feet in area, although it may be possible to employ one of the alternative runoff reduction practices on these lots (e.g., cistern, infiltration, etc.).
- Simple disconnection can be used on any post-construction Hydrologic Soil Group. However, for Soil Groups C or D, alternative runoff reduction practices (e.g., compost-amended filter path, rain garden, rainwater harvesting) can boost the runoff reduction rate. Also, erodibility of soils must be considered when designing simple disconnection.
- Maintenance of disconnected downspouts usually involves the regular lawn or landscaping maintenance in the filter path from the roof to the street. In some cases, runoff from a simple disconnection may be directed to a more natural, undisturbed setting (i.e., where lot grading and clearing is “fingerprinted” and the proposed filter path is protected).

Table 1.2: Simple Rooftop Disconnection Design Criteria [1]

DESIGN FACTOR	SIMPLE DISCONNECTION
Maximum impervious (Rooftop) Area Treated	1,000 sq. ft. per disconnection
Longest flow path (roof/gutter)	75 feet
Disconnection Length	Equal to longest flow path, but no less than 40 feet [2]
Disconnection slope	< 2%, or < 5% with turf reinforcement [3]
Distance from buildings or foundations	Extend downspouts 5 ft. [4] (15 ft. in karst areas) away from building *if grade is less than 1%*.
Type of Pretreatment	External (leaf screens, etc)

[1] For alternative runoff reduction practices, see the applicable specification for design criteria. See Table 1 in this specification for eligible practices and associated specification numbers.
[2] An alternative runoff reduction practice must be used when the disconnection length is less than 40 feet.
[3] Turf reinforcement may include EC-2, EC-3, or other appropriate reinforcing materials that are confirmed by the designer to be non-erosive for the specific characteristics and flow rates anticipated at each individual application, and acceptable to the plan approving authority.
[4] Note that the downspout extension of 5 feet is intended for simple foundations. The use of a dry well or french drain adjacent to an in-ground basement or finished floor area should be carefully designed and coordinated with the design of the structure’s water-proofing system (foundation drains, etc.), or avoided altogether.

3.2. Soil Compost-Amended Filter Path

The incorporation of compost amendments should conform to Stormwater Design Specification No. 4 (Soil Compost Amendments), and include the following design elements:

- Flow from the downspout should be spread over a 10-foot wide strip extending down-gradient along the flow path from the building to the street or conveyance system.
- The filter path should be at least 20 feet in length.
- A pea gravel or river stone diaphragm, or other accepted flow spreading device should be installed at the downspout outlet to distribute flows evenly across the filter path.
- The strip should have adequate “freeboard” so that flow remains within the strip and is not diverted away from the strip. In general, this means that the strip should be lower than the surrounding land area in order to keep flow in the filter path. Similarly, the flow area of the filter strip should be level to discourage concentrating the flow down the middle of the filter path.
- Use 2 to 4 inches of compost and till to a depth of 6 to 10 inches within the filter path.

3.3. Dry Wells and French Drains (Micro-Infiltration)

Depending on soil properties, roof runoff may be infiltrated into a shallow dry well or french drain. The design for this alternative should meet the requirements of micro-infiltration, as described in Stormwater Design Specification No. 8 (Infiltration), and summarized in **Table 1.3**. Note that the building setback of 5 feet is intended for simple foundations. The use of a dry well or french drain adjacent to an in-ground basement or finished floor area should be carefully designed and coordinated with the design of the structure’s water-proofing system (foundation drains, etc.), or avoided altogether.

Table 1.3. Micro-Infiltration Design Criteria

DESIGN FACTOR	MICRO-INFILTRATION DESIGN
Roof Area Treated	250 to 2,500 sq. ft.
Typical Practices	Dry Well and French Drain
Recommended Maximum Depth	3 feet
Runoff Reduction Sizing	See Specification No. 8: Infiltration
Minimum Soil Infiltration Rate	0.5 inches/hour
Observation Well	No
Type of Pretreatment	External (leaf screens, grass strip, etc)
UIC Permit Needed	No
Head Required	Nominal, 1 to 3 feet
Required Soil Test	One per practice
Building Setbacks	5 ft. down-gradient [1], 25 ft. up-gradient

[1] Note that the building setback of 5 feet is intended for simple foundations. The use of a dry well or french drain adjacent to an in-ground basement or finished floor area should be carefully designed and coordinated with the design of the structure’s water-proofing system (foundation drains, etc.), or avoided altogether.

In general, micro-infiltration areas will require a surface area up to 3% of the contributing roof area. An on-site soil test is needed to determine if soils are suitable for infiltration. It is recommended that the micro-infiltration facility be located in an expanded right-of-way or stormwater easement so that it can be accessed for maintenance.

3.4. Rain Gardens and Front Yard Bioretention (Micro-Bioretention)

Depending on soil properties, roof runoff may be filtered through a shallow bioretention area. The design for this option should meet the requirements of micro-bioretention (or Rain Garden), as described in Stormwater Design Specification No. 9 (Bioretention) and summarized in **Table 1.4**.

For some residential applications, front, side, and/or rear yard bioretention may be an attractive option. This form of bioretention captures roof, lawn, and driveway runoff from low- to medium-density residential lots in a depressed area (3 to 6 inches) between the home and the primary stormwater conveyance system (roadside ditch or pipe system). The bioretention area connects to the drainage system with an underdrain (connection to the drainage system must comply with the appropriate regulatory criteria). The concept is to take advantage of the drop from the roof leader to the conveyance system, by creating a 10-foot wide (minimum) bioretention corridor from roof to the street with a shallow (6 to 12 inch deep) temporary ponding area. The bioretention corridor must have a minimum effective length of at least 20 feet. The ponding area may have a turf or landscape cover, depending on homeowner preference. (The advantage of using micro-bioretention over a soil compost-amended filter path is the additional pollutant removal credit provided by bioretention.)

Table 1.4: Micro-Bioretention Design Criteria

DESIGN FACTOR	MICRO BIORETENTION (I.E., RAIN GARDEN)
Impervious Area Treated[1]	1,000 ft^2
Type of Inflow	Sheetflow or roof leader
Runoff Reduction Sizing[1]	Surface Area= 5% of roof area (Level 1); 6% of roof area (Level 2)
Minimum Soil Infiltration Rate	0.5 inches/hour (or use underdrain)
Observation Well/ Cleanout Pipes	No
Type of Pretreatment	External (leaf screens, etc)
Underdrain and gravel layer	Level 1: Yes; Level 2: Optional per soils[1]
Minimum Filter Media Depth	18 inches (Level 1); 24 inches (Level 2)
Media Source	Mixed on-site
Head Required	Nominal, 1 to 3 feet
Required Soil Borings	One, only when an underdrain is not used
Building Setbacks	5 ft down-gradient, 25 ft up-gradient
[1]Refer to Design Specification No. 9, Table 2, Micro-Bioretention for Level 1 and Level 2 Design Criteria, and sizing criteria for individual and multiple downspout applications.	

The bioretention media is 18 to 24 inches deep, and is located over a 12 to 24 inch deep stone reservoir (as required by the Micro-Bioretention design criteria – refer to Design Specification No. 9). A perforated underdrain is located above the stone reservoir, to promote storage and recharge, even on poorly draining soils. In urban settings, the underdrain is directly connected into the storm drain pipe running underneath the street or in the street right-of-way. A trench needs to be excavated during construction to connect the underdrain to the street storm drain system. Appropriate approvals are required for making any connections to a common (or public) drainage system.

Construction of the remainder of the front yard bioretention system is deferred until after the lot has been stabilized. The front yard design should reduce the risk of homeowner conversion because it allows the owners to choose whether they want turf or landscaping. Front yard bioretention requires regular mowing and/or landscape maintenance to perform effectively. It is recommended that the practice be located in an expanded right-of-way or stormwater easement so that it can be accessed in the event that it fails to drain properly.

3.5. Rain Tanks and Cisterns

This form of disconnection must conform to the design requirements outlined in Stormwater Design Specification No. 6 (Rain Tanks and Cisterns). The runoff reduction rates for rain tanks and cisterns depends on their storage capacity and ability to draw down water in between storms for reuse as potable water, grey-water or irrigation use. The actual runoff reduction rate for a particular design can be ascertained using the design spreadsheet referenced in Specification No. 6. All devices should have a suitable overflow area to route extreme flows into the next treatment practice or the stormwater conveyance system.

3.6. Stormwater Planter (Urban Bioretention)

This form of disconnection must conform to the design requirements for stormwater planters, as outlined in Appendix A of Stormwater Design Specification No. 9 (Urban Bioretention). Foundation planters are a useful option to disconnect and treat rooftop runoff, particularly in ultra-urban areas. They consist of confined planters that store and/or infiltrate runoff in a soil bed to reduce runoff volumes and pollutant loads. Stormwater planters combine an aesthetic landscaping feature with a functional form of stormwater treatment. Stormwater planters generally receive runoff from adjacent rooftop downspouts and are landscaped with plants that are tolerant to periods of both drought and inundation. The two basic design variations for stormwater planters are the infiltration planter and the filter planter.

An ***infiltration planter*** filters rooftop runoff through soil in the planter followed by infiltration into soils below the planter. The recommended minimum depth is 30 inches, with the shape and length determined by architectural considerations. The planter should be sized to temporarily store at least 1/2-inch of runoff from the contributing rooftop area in a reservoir above the planter bed. Infiltration planters should be placed at least 10 feet away from a building to prevent possible flooding or basement seepage damage.

A ***filter planter*** has an impervious liner on the bottom. The minimum planter depth is 18 inches, with the shape and length determined by architectural considerations. Runoff is temporarily stored in a reservoir located above the planter bed. Overflow pipes are installed to discharge runoff when maximum ponding depths are exceeded, to avoid water spilling over the side of the planter. In addition, an underdrain is used to carry runoff to the storm sewer system. Since a filter planter is self-contained and does not infiltrate into the ground, it can be installed right next to a building.

All planters should be placed at grade level or above ground. They should be sized to allow captured runoff to drain out within four hours after a storm event. Plant materials should be capable of withstanding moist and seasonally dry conditions. Planting media should have an infiltration rate of at least 2 inches per hour. The sand and gravel on the bottom of the planter should have a minimum infiltration rate of 5 inches per hour. The planter can be constructed of stone, concrete, brick, wood or other durable material. If treated wood is used, care should be taken so that trace metals and creosote do not leach out of the planter.

SECTION 4: MAINTENANCE

The rooftop disconnection and supplementary treatment device must be covered by a drainage easement to allow inspection and maintenance. When the disconnection occurs on a private residential lot, its existence and purpose must be noted on the deed of record. Homeowners must be provided a simple document that explains their purpose and routine maintenance needs. A deed restriction or other mechanism, enforceable by the qualifying local program, must be in place to help ensure that downspouts remain disconnected, treatment units are maintained and filtering/infiltrating areas are not converted or disturbed. The legal mechanism should, if possible, grant authority for local agencies to access the property for inspection or corrective action.

An example maintenance inspection checklist for Rooftop Disconnection can be accessed in Appendix C of Chapter 9 of the *Virginia Stormwater Management Handbook* (2010), and both and construction phase and maintenance inspection checklists can be found on the Center for Watershed Protection website at:

http://www.cwp.org/Resource_Library/Controlling_Runoff_and_Discharges/sm.htm
(scroll to Tool6: Plan Review, BMP Construction, and Maintenance Checklists)

SECTION 5: REGIONAL AND SPECIAL CASE DESIGN ADAPTATIONS

5.1 Karst Terrain

Rooftop disconnection is strongly recommended for most residential lots greater than 6,000 square feet, particularly if it can be combined with a secondary micro-practice to increase small scale runoff reduction. The discharge point from the disconnection should extend at least 15 feet from any building foundations. Rooftop disconnection is also recommended for commercial sites that are not likely to be stormwater hotspots.

5.2 Coastal Plain Terrain

Rooftop disconnection is strongly recommended in the coastal plain for roof or other impervious areas on most residential lots greater than 6,000 square feet, particularly if it can be combined with a secondary micro-practice to increase small-scale runoff reduction. The disconnection corridor should have a minimum slope of 1% and 2 feet of vertical separation from the water table.

SECTION 6: REFERENCES

City of Portland, Environmental Services. 2004. *Portland Stormwater Management Manual*. Portland, OR. http://www.portlandonline.com/bes/index.cfm?c=dfbbh

CWP. 2007. *National Pollutant Removal Performance Database Version 3.0*. Center for Watershed Protection, Ellicott City, MD.

Northern Virginia Regional Commission. 2007. *Low Impact Development Supplement to the Northern Virginia BMP Handbook*. Fairfax, Virginia.

Philadelphia Stormwater Management Guidance Manual. Available online at: http://www.phillyriverinfo.org/Programs/SubprogramMain.aspx?Id=StormwaterManual

Schueler, T., D. Hirschman, M. Novotney and J. Zielinski. 2007. *Urban stormwater retrofit practices*. Manual 3 in the Urban Subwatershed Restoration Manual Series. Center for Watershed Protection, Ellicott City, MD.

Schueler, T. 2008. Technical Support for the Baywide Runoff Reduction Method. Chesapeake Stormwater Network. Baltimore, MD. www.chesapeakestormwater.net

VIRGINIA DEQ STORMWATER
DESIGN SPECIFICATION No. 2

SHEET FLOW TO A VEGETATED FILTER STRIP OR CONSERVED OPEN SPACE

VERSION 1.9
March 1, 2011

SECTION 1. DESCRIPTION

Filter strips are vegetated areas that treat sheet flow delivered from adjacent impervious and managed turf areas by slowing runoff velocities and allowing sediment and attached pollutants to settle and/or be filtered by the vegetation. The two design variants of filter strips are (1) *Conserved Open Space* and (2) designed *Vegetated Filter Strips*. The design, installation, and management of these design variants are quite different, as outlined in this specification.

In both instances, stormwater must enter the filter strip or conserved open space as sheet flow. If the inflow is from a pipe or channel, an engineered level spreader must be designed in accordance with the criteria contained herein to convert the concentrated flow to sheet flow.

SECTION 2. PERFORMANCE

With proper design and maintenance, these practices can provide relatively high runoff reduction as shown in **Table 2.1**.

Table 2.1: Summary of Stormwater Functions Provided by Filter Strips [1]

Stormwater Function	Conservation Area		Vegetated Filter Strip	
	HSG Soils A and B	HSG Soils C and D	HSG Soils A	HSG Soils B [4], C and D
	Assume no CA [2] in Conservation Area		No CA [3]	With CA [2]
Annual Runoff Vol. Reduction (RR)	75%	50%	50%	50%
Total Phosphorus (TP) EMC Reduction[5] by BMP Treatment Process	0		0	
Total Phosphorus (TP) Mass Load Removal	75%	50%	50%	50%
Total Nitrogen (TN) EMC Reduction by BMP Treatment Process	0		0	
Total Nitrogen (TN) Mass Load Removal	75%	50%	50%	50%
Channel Protection and Flood Mitigation	**Partial.** Designers can use the RRM spreadsheet to adjust curve number for each design storm for the contributing drainage area; *and* designers can account for a lengthened Time-of-Concentration flow path in computing peak discharge.			

[1] CWP and CSN (2008); CWP (2007)
[2] CA = Compost Amended Soils (see Design Specification No. 4)
[3] Compost amendments are generally not applicable for undisturbed A soils, although it may be advisable to incorporate them on mass-graded A or B soils and/or filter strips on B soils, in order to maintain runoff reduction rates.
[4] The plan approving authority may waive the requirement for compost amended soils for filter strips on B soils under certain conditions (see Section 6.2 below)
[5] There is insufficient monitoring data to assign a nutrient removal rate for filter strips at this time.

SECTION 3. DESIGN TABLE

Conserved Open Space and Vegetated Filter Strips do not have two levels of design. Instead, each must meet the appropriate minimum criteria outlined in **Table 2.2** (next page) and **Section 6** (below) to qualify for the indicated level of runoff reduction. In addition, designers must conduct a site reconnaissance prior to design to confirm topography and soil conditions.

SECTION 4. TYPICAL DETAILS

Figure 1 shows a typical approach for sheetflow to a Conserved Open Space (Cappiella *et al*., 2006). **Figures 2 and 3** provide standard details for an engineered level spreader developed by North Carolina State University (Hathaway and Hunt, 2006). An alternative design for an "energy dissipater" can be found in Henrico County's *Environmental Program Manual* (Chapter 9, Minimum Design Standard 9.01) at: http://www.co.henrico.va.us/works/eesd/

Table 2.2. Filter Strip Design Criteria

Design Issue	Conserved Open Space	Vegetated Filter Strip
Soil and Vegetative Cover (Sections 6.1 and 6.2)	Undisturbed soils and native vegetation	Amended soils and dense turf cover or landscaped with herbaceous cover, shrubs, and trees
Overall Slope and Width (perpendicular to the flow) (Section 5)	0.5% to 3% Slope – Minimum 35 ft width 3% to 6% Slope – Minimum 50 ft width The first 10 ft. of filter must be 2% or less in all cases [2]	1% [1] to 4% Slope – Minimum 35 ft. width 4% to 6% Slope – Minimum 50 ft. width 6% to 8% Slope – Minimum 65 ft. width The first 10 ft. of filter must be 2% or less in all cases
Sheet Flow (Section 5)	Maximum flow length of 150 ft. from adjacent pervious areas; Maximum flow length of 75 ft. from adjacent impervious areas	
Concentrated Flow (Section 6.3)	Length of ELS [6] Lip = 13 lin. ft. per each 1 cfs of inflow if area has 90% Cover [3] Length = 40 lin. ft. per 1 cfs for forested or re-forested Areas [4] (ELS [6] length = 13 lin.ft. min; 130 lin.ft. max.)	Length of ELS [6] Lip = 13 lin.ft. per each 1 cfs of inflow (13 lin.ft. min; 130 lni.ft. max.)
Construction Stage (Section 8)	Located outside the limits of disturbance and protected by ESC controls	Prevent soil compaction by heavy equipment
Typical Applications (Section 5)	Adjacent to stream or wetland buffer or forest conservation area	Treat small areas of IC (e.g., 5,000 sf) and/or turf-intensive land uses (sports fields, golf courses) close to source
Compost Amendments (Section 6.1)	No	Yes (B, C, and D soils) [5]
Boundary Spreader (Section 6.3)	GD [6] at top of filter	GD [6] at top of filter PB [6] at toe of filter

[1] A minimum of 1% is recommended to ensure positive drainage.

[2] For Conservation Areas with a varying slope, a pro-rated length may be computed only if the first 10 ft. is 2% or less.

[3] Vegetative Cover is described in **Section 6.2**.

[4] Where the Conserved Open Space is a mixture of native grasses, herbaceous cover and forest (or re-forested area), the length of the ELS [6] Lip can be established by computing a weighted average of the lengths required for each vegetation type. Refer to **Section 6.3** for design criteria

[5] The plan approving authority may waive the requirement for compost amended soils for filter strips on B soils under certain conditions (see **Section 6.1**).

[6] ELS = Engineered Level Spreader; GD = Gravel Diaphragm; PB = Permeable Berm.

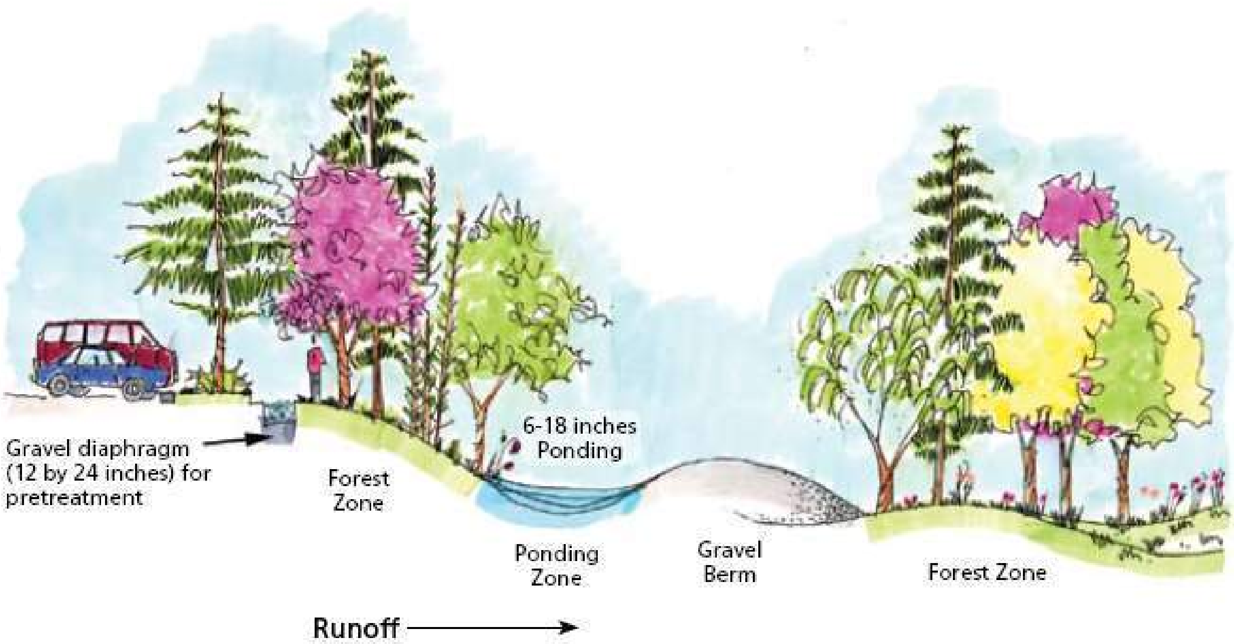


Figure 2.1. Typical Sheetflow to Conserved Open Space

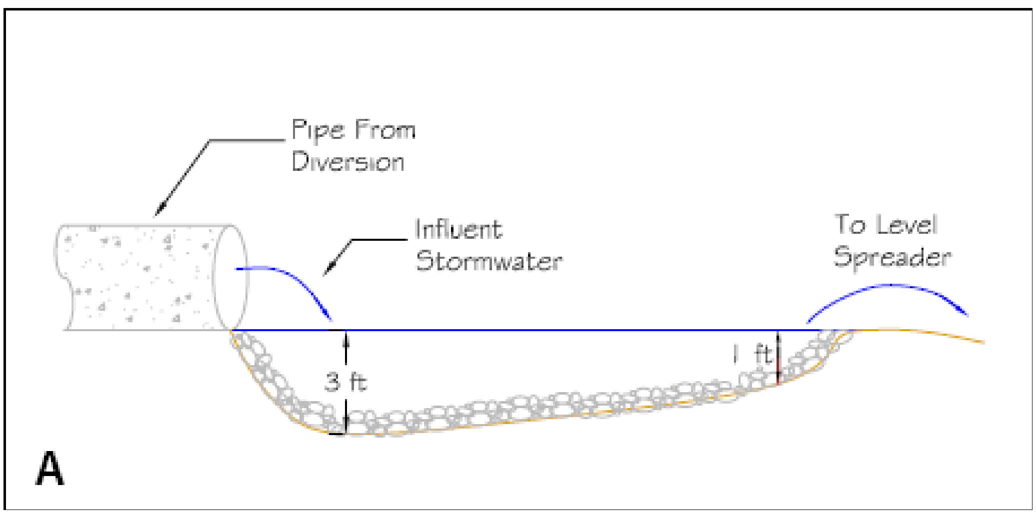


Figure 2.2. Level Spreader Forebay (Hathaway and Hunt 2006)

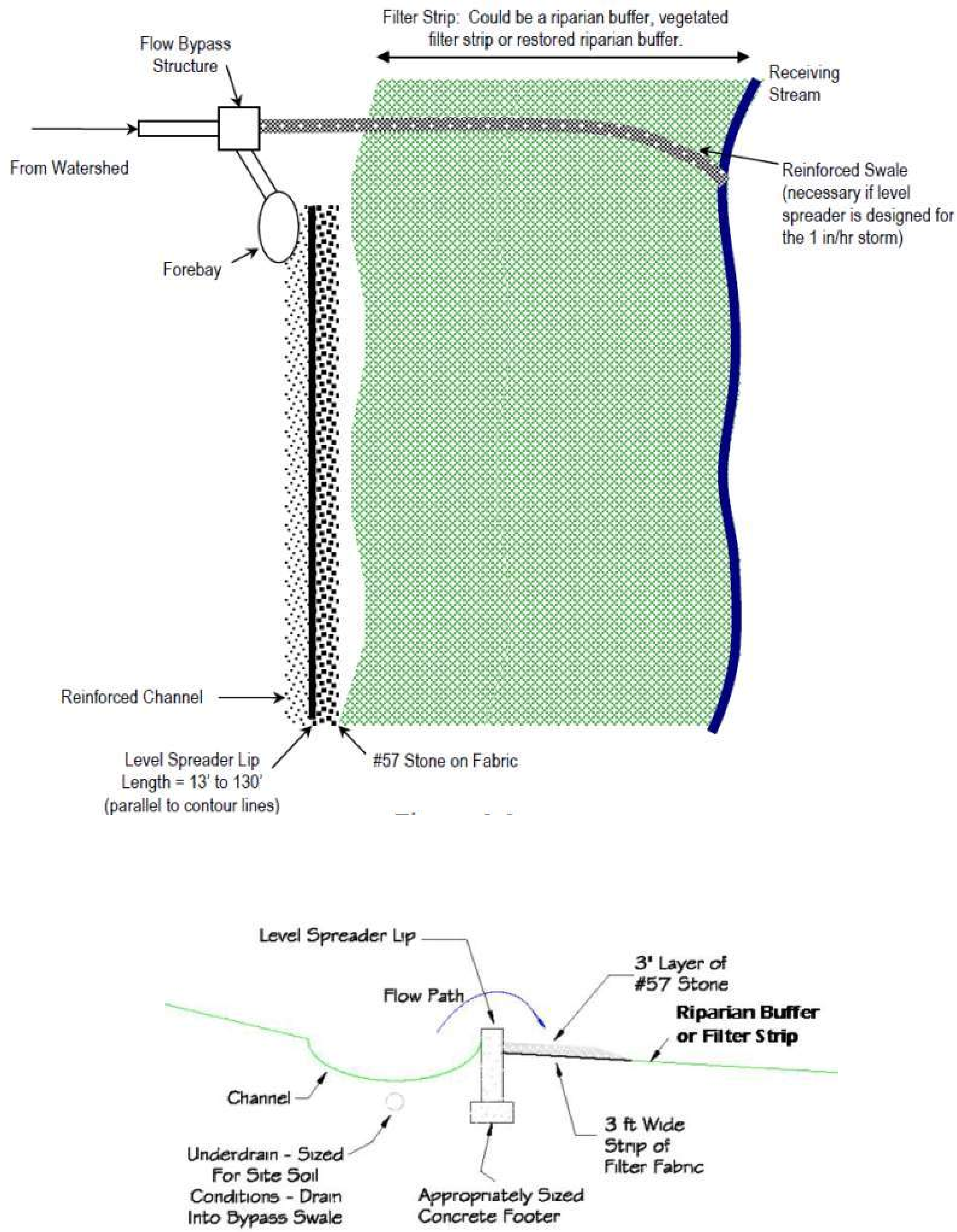


Figure 2.3: Plan and Cross Section of Engineered Level Spreader (ELS) (Hathaway 2006)

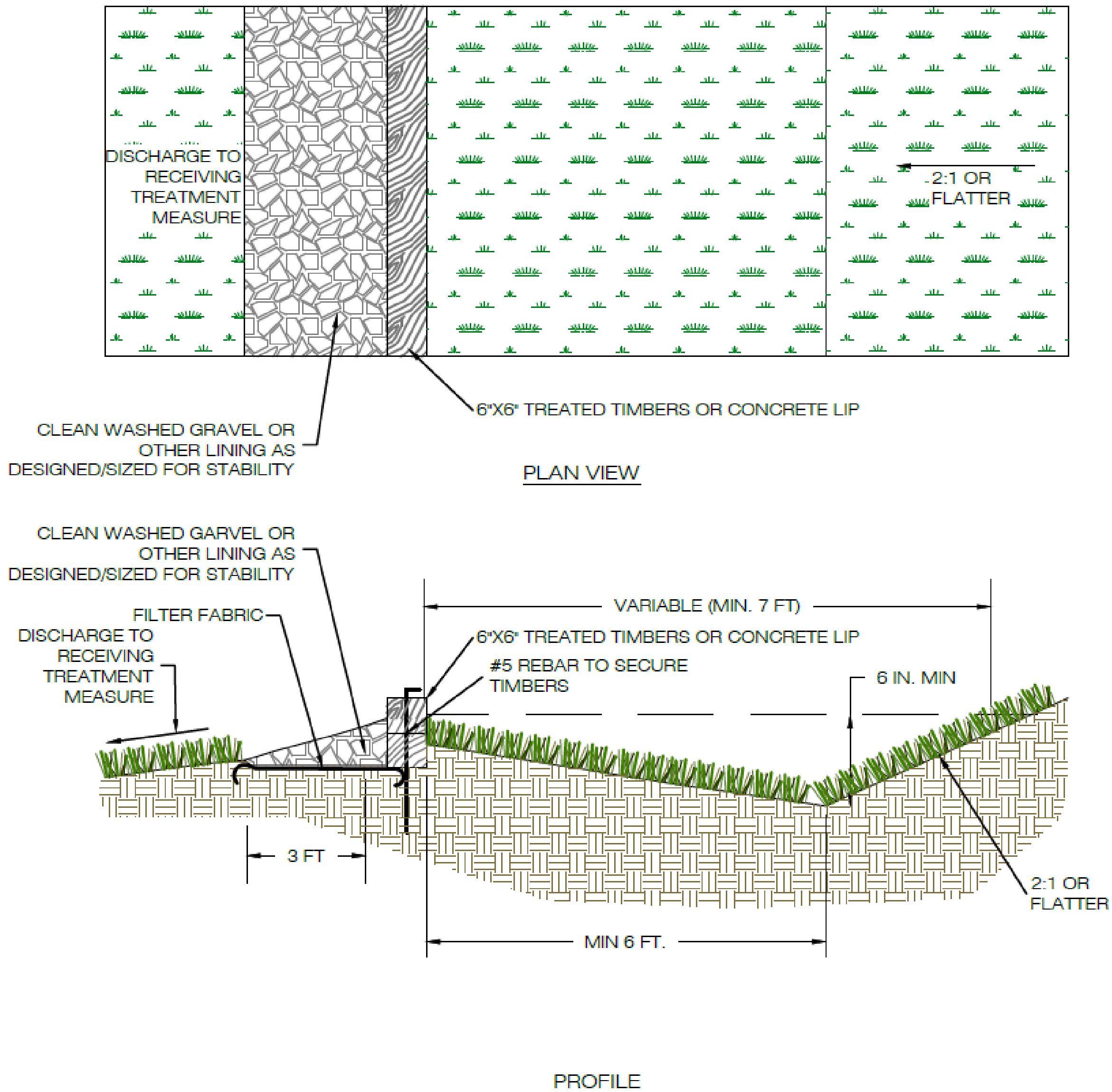


Figure 2.4A: Section - Level Spreader with Rigid Lip

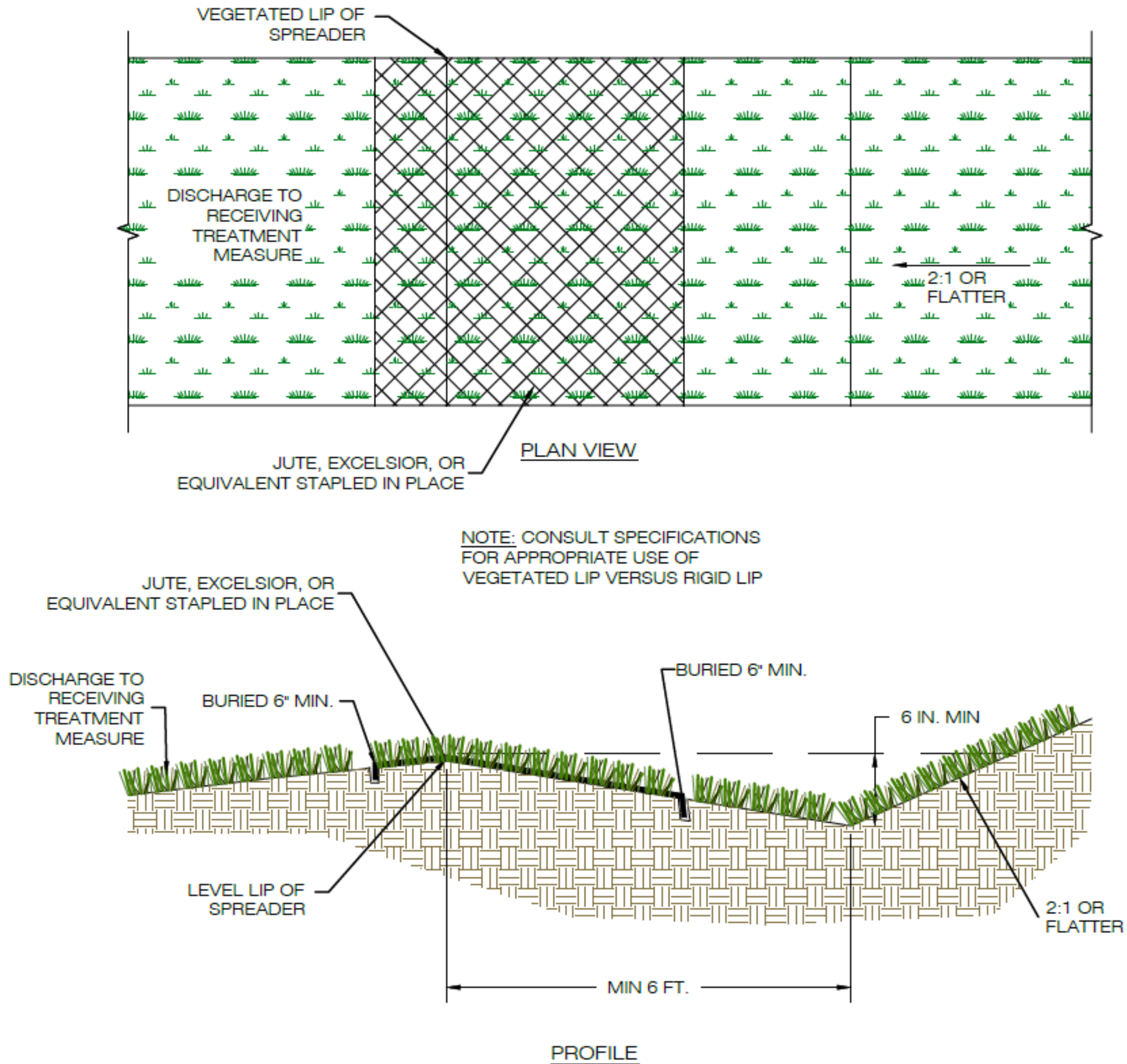


Figure 2.4B: Section - Alternative Level Spreader with Vegetated Lip

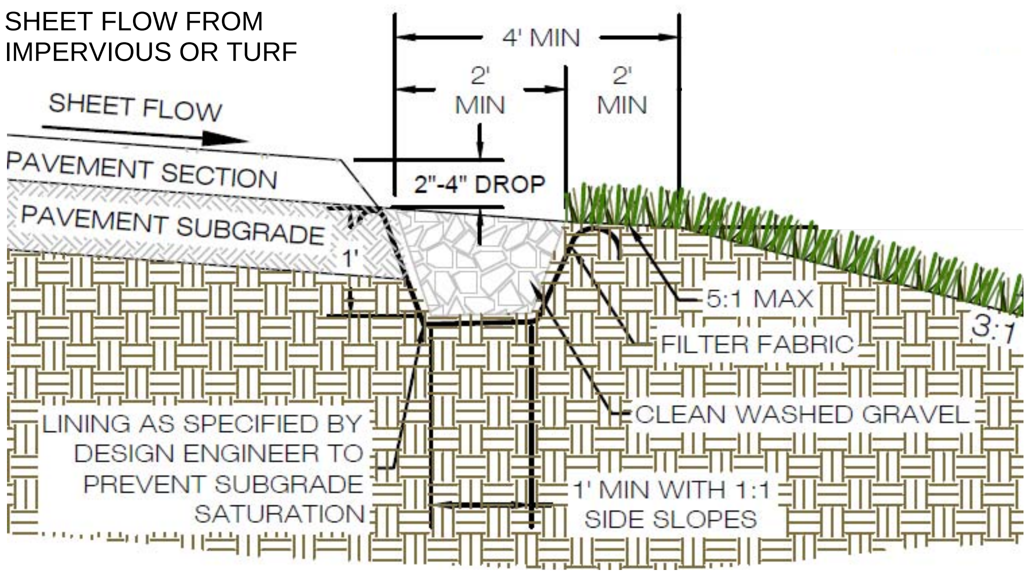


Figure 2.5 – Gravel Diaphragm – Sheet Flow Pre-treatment

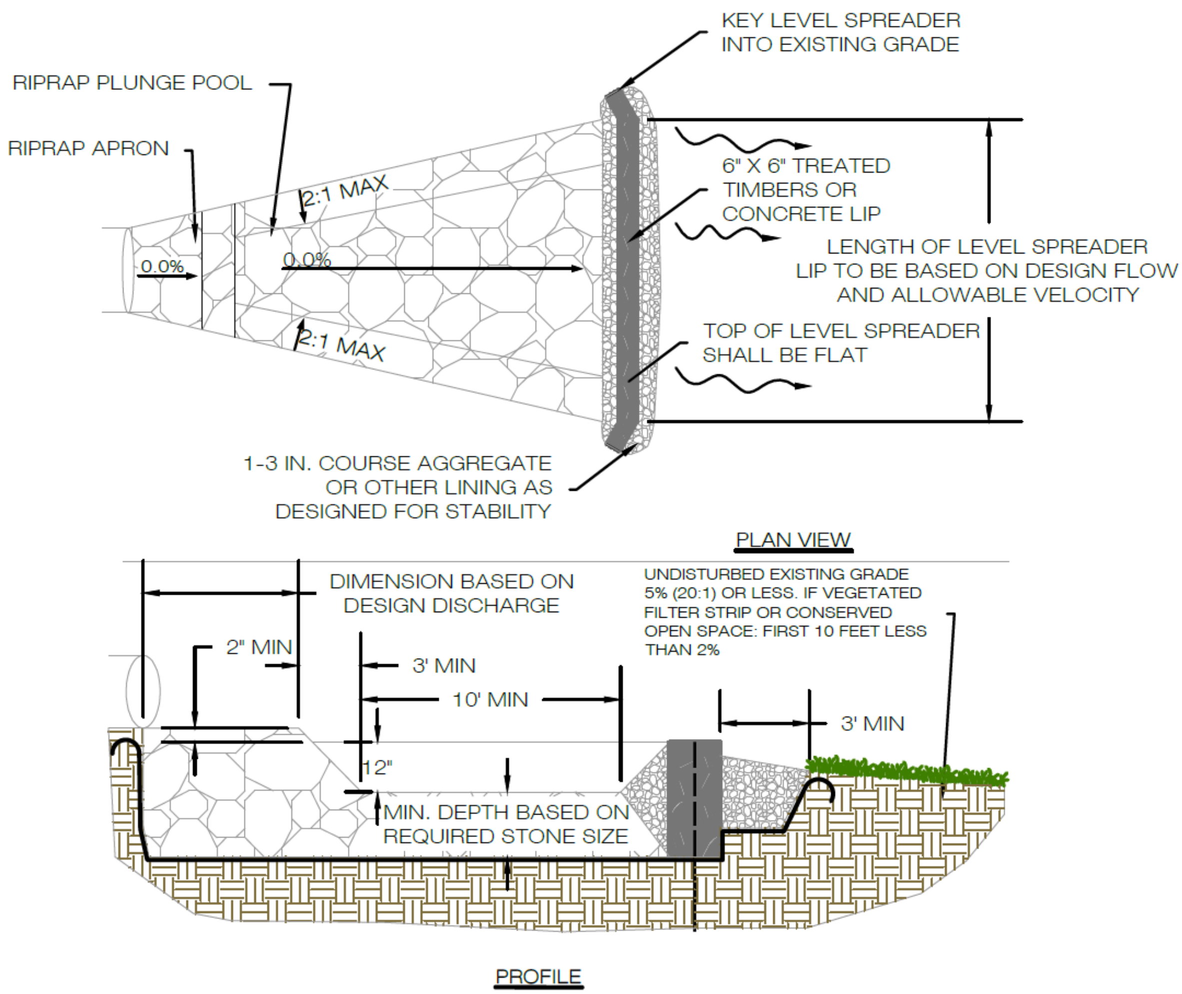


Figure 2.6: Level Spreader: Pipe or Channel Flow to Filter Strip or Preserved Open Space

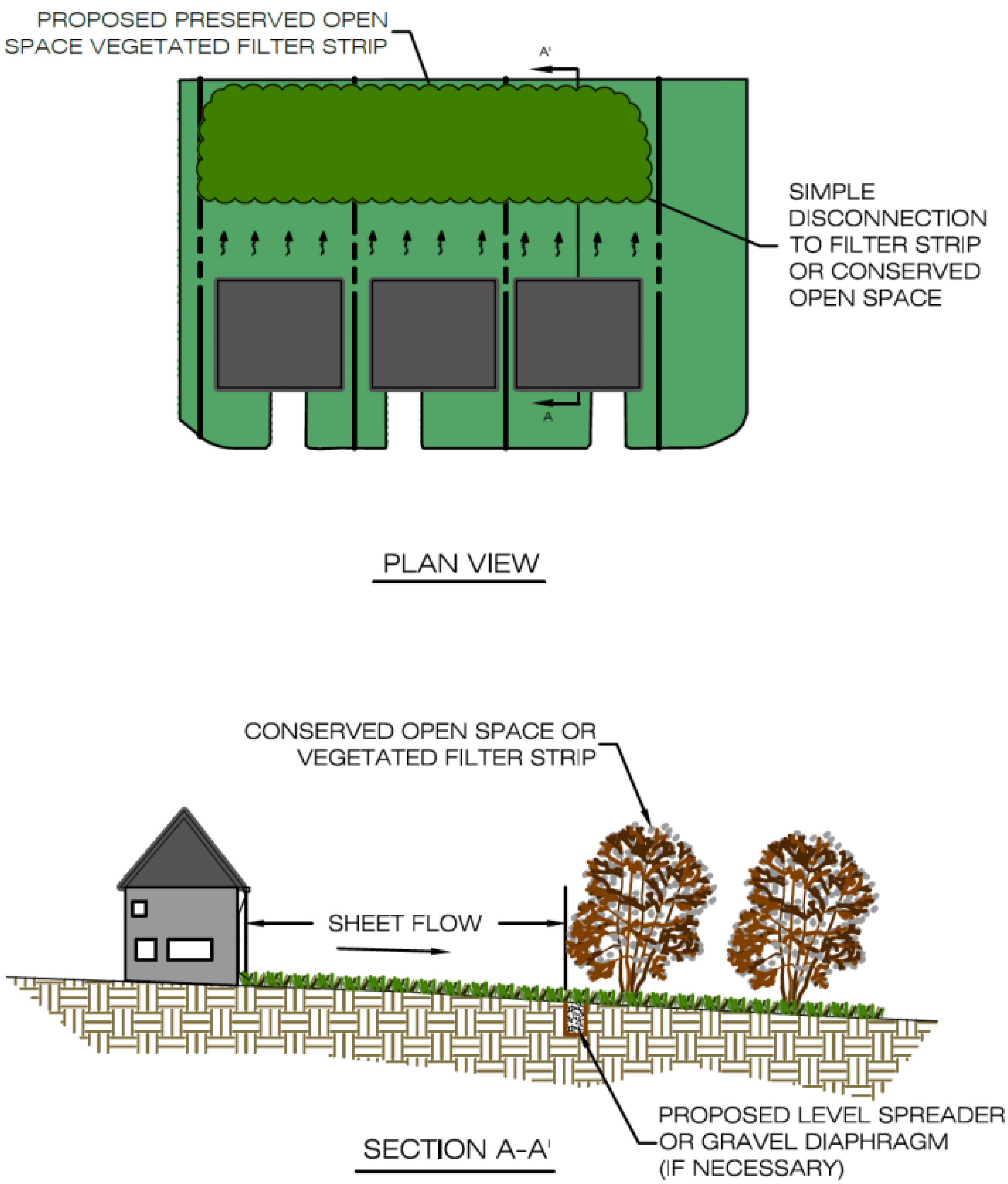


Figure 2.7: Simple Disconnection to downstream Preserved Open Space or Vegetated Filter Strip

SECTION 5. PHYSICAL FEASIBILITY & DESIGN APPLICATIONS

5.1 Conserved Open Space

The most common design applications of Conserved Open Space are on sites that are hydrologically connected to a protected stream buffer, wetland buffer, floodplain, forest conservation area, or other protected lands. Conserved open space is an ideal component of the "outer zone" of a stream buffer, such as a Resource Protection Area (as is required in some parts of the state), which normally receives runoff as sheetflow. Care should be taken to locate all energy dissipaters or flow spreading devices outside of the protected area.

Designers may apply a runoff reduction credit to any impervious or managed turf cover that is hydrologically connected and effectively treated by a protected Conserved Open Space that meets the following eligibility criteria:

- The goal of establishing Conserved Open Space is to protect a vegetated area contiguous to a receiving system, such as a stream or natural channel, for treating stormwater runoff. Establishing isolated Conserved Open Space pockets on a development site may not achieve this goal unless they effectively serve to connect the surface runoff to the receiving system. Therefore, a locality may choose to establish goals for minimum acreage to be conserved (in terms of total acreage or percentage of the total project site), and the physical location (adjacent to a stream, or other criteria) in order for the cumulative conserved open space to qualify for the RRM credit.
- No major disturbance may occur within the conserved open space during or after construction (i.e., no clearing or grading is allowed except temporary disturbances associated with incidental utility construction, restoration operations, or management of nuisance vegetation). The Conserved Open Space area shall not be stripped of topsoil. Some light grading may be needed at the boundary using tracked vehicles to prevent compaction.
- The limits of disturbance should be clearly shown on all construction drawings and protected by acceptable signage and erosion control measures.
- A long term vegetation management plan must be prepared to maintain the Conserved Open Space in a natural vegetative condition. Generally, Conserved Open Space management plans do not encourage or even allow any active management. However, a specific plan should be developed to manage the unintended consequences of passive recreation, control invasive species, provide for tree and understory maintenance, etc. Managed turf is not considered an acceptable form of vegetative management, and only the passive recreation areas of dedicated parkland are eligible for the practice (e.g., the actively used portions of ball fields and golf courses are not eligible), although conservation areas can be ideal treatment practices at the edges of turf-intensive land uses.
- The Conserved Open Space must be protected by a perpetual easement or deed restriction that assigns the responsible party to ensure that no future development, disturbance, or clearing may occur within the area.
- The practice does *not* apply to jurisdictional wetlands that are sensitive to increased inputs of stormwater runoff (e.g., bogs and fens).

5.2 Vegetated Filter Strips

Vegetated Filter Strips are best suited to treat runoff from small segments of impervious cover (usually less than 5,000 sq. ft.) adjacent to road shoulders, small parking lots and rooftops. Vegetated Filter Strips may also be used as pretreatment for another stormwater practice such as a dry swale, bioretention, or infiltration areas. If sufficient pervious area is available at the site, larger areas of impervious cover can be treated by vegetated filter strips, using an engineered level spreader to recreate sheet flow. Vegetated Filter Strips are also well suited to treat runoff from turf-intensive land uses, such as the managed turf areas of sports fields, golf courses, and parkland.

Conserved Open Space and Vegetated Filter Strips can be used in a variety of situations; however there are several constraints to their use:

- ***Filter Slopes and Widths.*** Maximum slopes for Conserved Open Space and Vegetated Filter Strips are 6% and 8% respectively, in order to maintain sheet flow through the practice. In addition, the overall contributing drainage area must likewise be relatively flat to ensure sheet flow draining into the filter. Where this is not possible, alternative measures, such as an engineered level spreader, can be used. Minimum widths (flow path) for Conserved Open Space and Vegetated Filter Strips are dependent on slope, as specified in **Table 2.2** above.

- ***Soils.*** Vegetated Filter Strips are appropriate for all soil types, except fill soils. The runoff reduction rate, however, is dependent on the underlying Hydrologic Soil Groups (see **Table 2.1** above) and whether soils receive compost amendments.

- ***Contributing Flow Path to Filter.*** Vegetated Filter Strips are used to treat very small drainage areas of a few acres or less. The limiting design factor is the length of flow directed to the filter. As a rule, flow tends to concentrate after 75 feet of flow length for impervious surfaces, and 150 feet for pervious surfaces (Claytor, 1996). When flow concentrates, it moves too rapidly to be effectively treated by a Vegetated Filter Strip, unless an engineered level spreader is used. When the existing flow at a site is concentrated, a vegetated swale should be used instead of a Vegetated Filter Strip (Lantin and Barrett, 2005).

- ***Hotspot Land Uses.*** Vegetated Filter Strips should not receive hotspot runoff, since the infiltrated runoff could cause groundwater contamination.

- ***Turf-Intensive Land Uses.*** Both Conserved Open Space and Vegetated Filter Strips are appropriate to treat managed turf and the actively-used areas of sports fields, golf courses, parkland, and other turf-intensive land uses.

- ***Proximity of Underground Utilities.*** Underground pipes and conduits that cross the Vegetated Filter Strip are acceptable.

SECTION 6. DESIGN CRITERIA

6.1. Compost Soil Amendments

Compost soil amendments will enhance the runoff reduction capability of a vegetated filter strip when located on hydrologic soil groups B, C, and D, subject to the following design requirements:

- The compost amendments should extend over the full length and width of the filter strip.
- The amount of approved compost material and the depth to which it must be incorporated is outlined in Stormwater Design Specification No. 4.
- The amended area will be raked to achieve the most level slope possible without using heavy construction equipment, and it will be stabilized rapidly with perennial grass and/or herbaceous species.
- If slopes exceed 3%, a protective biodegradable fabric or matting (e.g., EC-2) should be installed to stabilize the site prior to runoff discharge.
- Compost amendments should not be incorporated until the gravel diaphragm and/or engineered level spreader are installed (see **Section 6.3**).
- The local plan approval authority may waive the requirement for compost amendments on HSG-B soils in order to receive credit as a filter strip if (1) the designer can provide verification of the adequacy of the on-site soil type, texture, and profile to function as a filter strip, and (2) the area designated for the filter strip will not be disturbed during construction.

6.2. Planting and Vegetation Management

***Conserved Open Space* .** No grading or clearing of native vegetation is allowed within the Conserved Open Space. An invasive species management plan should be developed and approved by the local plan approval authority.

Reforested Conserved Open Space. At some sites, the proposed stream buffer or Conserved Open Space may be in turf or meadow cover, or overrun with invasive plants and vines. In these situations, a landscape architect or horticulturalist should prepare a reforestation or restoration plan for the Conserved Open Space. The entire area can be planted with native trees and shrubs or planted to achieve a gradual transition from turf to meadow to shrub and forest. Trees and shrubs with deep rooting capabilities are recommended for planting to maximize soil infiltration capacity (PWD, 2007). Over-plant with seedlings for fast establishment and to account for mortality. Plant larger stock at desired spacing intervals (25 to 40 feet for large trees) using random spacing (Cappiella *et al*., 2006). Plant ground cover or a herbaceous layer to ensure rapid vegetative cover of the surface area.

Vegetated Filter Strips. Vegetated Filter Strips should be planted at such a density to achieve a 90% grass/herbaceous cover after the second growing season. Filter strips should be seeded, not sodded. Seeding establishes deeper roots, and sod may have muck soil that is not conducive to infiltration (Wisconsin DNR, 2007). The filter strip vegetation may consist of turf grasses, meadow grasses, other herbaceous plants, shrubs, and trees, as long as the primary goal of at least 90% coverage with grasses and/or other herbaceous plants is achieved. Designers should choose vegetation that stabilizes the soil and is salt tolerant. Vegetation at the toe of the filter, where temporary ponding may occur behind the permeable berm, should be able to withstand both wet and dry periods. The planting areas can be divided into zones to account for differences in inundation and slope.

6.3. Diaphragms, Berms and Level Spreaders

Gravel Diaphragms: A pea gravel diaphragm at the top of the slope is required for both Conserved Open Space and Vegetated Filter Strips that receive sheetflow. The pea gravel diaphragm is created by excavating a 2-foot wide and 1-foot deep trench that runs on the same contour at the top of the filter strip. The diaphragm serves two purposes. First, it acts as a pretreatment device, settling out sediment particles before they reach the practice. Second, it acts as a level spreader, maintaining sheet flow as runoff flows over the Filter Strip. Refer to **Figure 2.5.**

- The flow should travel over the impervious area and to the practice as sheet flow and then drop at least 3 inches onto the gravel diaphragm. The drop helps to prevent runoff from running laterally along the pavement edge, where grit and debris tend to build up (thus allowing by-pass of the Filter Strip).
- A layer of filter fabric should be placed between the gravel and the underlying soil trench.
- If the contributing drainage area is steep (6% slope or greater), then larger stone (clean bank-run gravel that meets VDOT #57 grade) should be used in the diaphragm.
- If the contributing drainage area is solely turf (e.g., sports field), then the gravel diaphragm may be eliminated.

Permeable Berm: Vegetated Filter Strips should be designed with a permeable berm at the toe of the Filter Strip to create a shallow ponding area. Runoff ponds behind the berm and gradually flows through outlet pipes in the berm or through a gravel lens in the berm with a perforated pipe. During larger storms, runoff may overtop the berm (Cappiella *et al.*, 2006). The permeable berm should have the following properties:

- A wide and shallow trench, 6 to 12 inches deep, should be excavated at the upstream toe of the berm, parallel with the contours.
- Media for the berm should consist of 40% excavated soil, 40% sand, and 20% pea gravel.
- The berm 6 to 12 inches high should be located downgradient of the excavated depression and should have gentle side slopes to promote easy mowing (Cappiella *et al*., 2006).
- Stone may be needed to armor the top of berm to handle extreme storm events.
- A permeable berm is not needed when vegetated filter strips are used as pretreatment to another stormwater practice.

Engineered Level Spreaders. The design of engineered level spreaders should conform to the following design criteria based on recommendations of Hathaway and Hunt (2006), or a locally approved standard that meets the intent of these criteria, in order to ensure non-erosive sheet flow into the vegetated buffer area. **Figure 2.3** above represents a configuration that includes a bypass structure that diverts the design storm to the level spreader, and bypasses the larger storm events around the Conserved Open Space or Vegetated Filter Strip through an improved channel.

An alternative approach is that utilized by Henrico County, where pipe or channels discharge at the landward edge of a floodplain or stream (Resource Protection Area or RPA) buffer. The entire flow is directed through a stilling basin energy dissipater and then a level spreader such that the entire design storm for the conveyance system (typically a 10-year frequency storm) is discharged as sheet flow through the buffer. (Refer to Henrico County's *Environmental Program Manual;* Chapter 9, Minimum Design Standard 9.01 "Energy Dissipator": http://www.co.henrico.va.us/works/eesd/ .)

Key design elements of the engineered level spreader, as provided in **Figures 2 and 3**, include the following:

- High Flow Bypass provides safe passage for larger design storms through the filter strip. The bypass channel should accommodate all peak flows greater than the water quality design flow.
- A Forebay should have a maximum depth of 3 feet and gradually transition to a depth of 1 foot at the level spreader lip (**Figure 2**). The forebay is sized such that the surface area is 0.2% of the contributing impervious area. (A forebay is not necessary if the concentrated flow is from the outlet of an extended detention basin or similar practice).
- The length of the level spreader should be determined by the type of filter area and the design flow:
  - 13 feet of level spreader length per every 1 cubic foot per second (cfs) of inflow for discharges to a Vegetated Filter Strip or Conserved Open Space consisting of native grasses or thick ground cover;
  - 40 feet of level spreader length per every 1 cfs of inflow when the spreader discharges to a Conserved Open Space consisting of forested or reforested buffer (Hathaway and Hunt, 2006).
  - Where the Conserved Open Space is a mix of grass and forest (or re-forested), establish the level spreader length by computing a weighted average of the lengths required for each vegetation type.
  - The minimum level spreader length is 13 feet and the maximum is 130 feet.
  - For the purposes of determining the Level Spreader length, the peak discharge shall be determined using the Rational Equation with an intensity of 1-inch/hour.

- The level spreader lip should be concrete, wood or pre-fabricated metal, with a well-anchored footer, or other accepted rigid, non-erodible material.
- The ends of the level spreader section should be tied back into the slope to avoid scouring around the ends of the level spreader; otherwise, short-circuiting of the facility could create erosion.
- The width of the level spreader channel on the up-stream side of the level lip should be three times the diameter of the inflow pipe, and the depth should be 9 inches or one-half the culvert diameter, whichever is greater.
- The level spreader should be placed 3 to 6 inches above the downstream natural grade elevation to avoid turf buildup. In order to prevent grade drops that re-concentrate the flows, a 3-foot long section of VDOT # 3 stone, underlain by filter fabric, should be installed just below the spreader to transition from the level spreader to natural grade.

- Vegetated receiving areas down-gradient from the level spreader must be able to withstand the force of the flow coming over the lip of the device. It may be necessary to stabilize this area with temporary (VDOT EC-2) or permanent (VDOT EC-3) materials in accordance with the calculated velocity (on-line system peak, or diverted off-line peak) and material specifications, along with seeding and stabilization in conformance with the Virginia Erosion and Sediment Control Handbook.

6.4. Filter Design Material Specifications

Table 2.3 describes materials specifications for the primary treatment within filter strips.

Table 2.3. Vegetated Filter Strip Materials Specifications

Material	Specification	Quantity
Gravel Diaphragm	Pea Gravel (#8 or ASTM equivalent) or where steep (6% +) use clean bank-run VDOT #57 or ASTM equivalent (1-inch maximum).	Diaphragm should be 2 feet wide, 1 foot deep, and at least 3 inches below the edge of pavement.
Permeable Berm	40% excavated soil, 40% sand, and 20% pea gravel to serve as the media for the berm.	
Geotextile	Needled, non-woven, polypropylene geotextile meeting the following specifications: Grab Tensile Strength (ASTM D4632): > 120 lbs. Mullen Burst Strength (ASTM D3786): > 225 lbs./sq. in. Flow Rate (ASTM D4491): > 125 gpm/sq. ft. Apparent Opening Size (ASTM D4751): US #70 or #80 sieve	
Engineered Level Spreader	Level Spreader lip should be concrete, metal, timber, or other rigid material; Reinforced channel on upstream of lip: VDOT EC-2 (or EC-3 if velocities require permanent reinforcing). See Hathaway and Hunt (2006) or Henrico County Program Manual.	
Erosion Control Fabric or Matting	Where flow velocities dictate, use woven biodegradable erosion control fabric or mats that are durable enough to last at least 2 growing seasons. (e.g., VDOT Erosion Control matting EC-2).	
Topsoil	If existing topsoil is inadequate to support dense turf growth, imported top soil (loamy sand or sandy loam texture), with less than 5% clay content, corrected pH at 6 to 7, a soluble salt content not exceeding 500 ppm, and an organic matter content of at least 2% shall be used. Topsoil shall be uniformly distributed and lightly compacted to a minimum depth of 6 to 8 inches	
Compost	Compost shall be derived from plant material and provided by a member of the U.S. Composting Seal of Testing Assurance (STA) program, as outlined in Stormwater Design Specification No. 4.	

SECTION 7: REGIONAL & SPECIAL CASE DESIGN ADAPTATIONS

7.1. Karst Terrain

Conserved Open Space areas are highly recommended in karst terrain, particularly when storm flow discharges to the outer boundary of a karst protection area (see CSN, 2009).

Vegetated Filter Strips can also be used to treat runoff from small areas of impervious cover (e.g., less than 5,000 square feet). Some communities use wide grass filter strips to treat runoff from the roadway shoulder.

In no case should the use of a Conserved Open Space or Vegetated Filter Strip be considered as a replacement for an adequate receiving system for developed-condition stormwater discharges, unless the adequacy of the design has been demonstrated consistent with the the Virginia Stormwater Management Handbook.

7.2. Coastal Plain

The use of Conserved Open Space areas and Vegetated Filter Strips are highly recommended in the coastal plain, particularly when sheetflow (or concentrated flow with an appropriately-sized level spreader) discharges to the outer boundary of a shoreline, stream or wetland buffer. Vegetated Filter Strips can also be used to treat runoff from small areas of impervious cover (e.g., less than 5,000 square feet). In both cases, however, the designer must consider the depth to the water table. In general, shallow water tables may inhibit the function of Vegetated Filter Strips.

7.3. Linear Highway Sites

Vegetated Filter Strips are highly recommended to treat highway runoff if the median and/or road shoulder is wide enough to provide an adequate flow path.

SECTION 8: CONSTRUCTION

8.1. Construction Sequence for Conserved Open Space Areas

The Conserved Open Space must be fully protected during the construction stage of development and kept outside the limits of disturbance on the Erosion and Sediment (E&S) Control Plan.

- No clearing, grading or heavy equipment access is allowed except temporary disturbances associated with incidental utility construction, restoration operations or management of nuisance vegetation.
- The perimeter of the Conserved Open Space shall be protected by super silt fence, chain link fence, orange safety fence, or other measures to prevent sediment discharge.
- The limits of disturbance should be clearly shown on all construction drawings and identified and protected in the field by acceptable signage, silt fence, snow fence or other protective barrier.

- Construction of the gravel diaphragm or engineered level spreader shall not commence until the contributing drainage area has been stabilized and perimeter E&S controls have been removed and cleaned out.
- Some light grading may be needed at the Filter Strip boundary; this should be done with tracked vehicles to prevent compaction.
- Stormwater should not be diverted into the Vegetated Filter Strip until the gravel diaphragm and/or level spreader are installed and stabilized.

8.2. Construction Sequence for Vegetated Filter Strips

Vegetated Filter Strips can be within the limits of disturbance during construction. The following procedures should be followed during construction:

- Before site work begins, Vegetated Filter Strip boundaries should be clearly marked.
- Only vehicular traffic used for Filter Strip construction should be allowed within 10 feet of the Filter Strip boundary (City of Portland, 2004).
- If existing topsoil is stripped during grading, it shall be stockpiled for later use.
- Construction runoff should be directed away from the proposed Filter Strip site, using perimeter silt fence, or, preferably, a diversion dike.
- Construction of the gravel diaphragm or engineered level spreader shall not commence until the contributing drainage area has been stabilized and perimeter E&S controls have been removed and cleaned out.
- Vegetated Filter Strips require light grading to achieve desired elevations and slopes. This should be done with tracked vehicles to prevent compaction. Topsoil and or compost amendments should be incorporated evenly across the filter strip area, stabilized with seed, and protected by biodegradable erosion control matting or blankets.
- Stormwater should not be diverted into the Filter Strip until the turf cover is dense and well established.

8.3. Construction Inspection

Construction inspection is critical to obtain adequate spot elevations, to ensure the gravel diaphragm or ELS is completely level, on the same contour, and constructed to the correct design elevation. As-built surveys should be required to ensure compliance with design standards. Inspectors should evaluate the performance of the Filter Strip after the first big storm to look for evidence of gullies, outflanking, undercutting or sparse vegetative cover. Spot repairs should be made, as needed.

An example construction phase inspection checklist for Sheet Flow to a Filter Strip or Conserved Open Space can be found on the Center for Watershed Protection website at:

http://www.cwp.org/Resource_Library/Controlling_Runoff_and_Discharges/sm.htm
(scroll to Tool6: Plan Review, BMP Construction, and Maintenance Checklists)

SECTION 9. MAINTENANCE

9.1. Maintenance Agreements

Section 4 VAC 50-60-124 of the regulations specifies the circumstances under which a maintenance agreement must be executed between the owner and the local program. This section sets forth inspection requirements, compliance procedures if maintenance is neglected, notification of the local program upon transfer of ownership, and right-of-entry for local program personnel.

All Vegetated Filter Strips must be covered by a drainage easement to allow inspection and maintenance. If the filter area is a natural Conserved Open Space, it must be protected by a perpetual easement or deed restriction that assigns the responsible party to ensure that no future development, disturbance or clearing may occur within the area, except as stipulated in the vegetation maintenance plan.

If the Vegetated Filter Strip is located on a residential private lot, the existence and purpose of the Filter Strip shall be noted on the deed of record. Homeowners will need to be provided a simple document that explains the purpose of the Filter Strip and routine maintenance needs. A deed restriction or other mechanism enforceable by the qualifying local program must be in place to help ensure that Filter Strips are maintained and Conserved Open Space Areas are not converted or disturbed. The mechanism should, if possible, grant authority for local agencies to access the property for inspection or corrective action.

9.2. Maintenance Inspections

Annual inspections are used to trigger maintenance operations such as sediment removal, spot re-vegetation and level spreader repair. Ideally, inspections should be conducted in the non-growing season when it easier to see the flow path. Example maintenance inspection checklists for Sheet Flow to a Filter Strip or Conserved Open Space areas can be accessed in Appendix C of Chapter 9 of the Virginia Stormwater Management Handbook or at the Center for Watershed Protection's website at:

http://www.cwp.org/Resource_Library/Controlling_Runoff_and_Discharges/sm.htm
(scroll to Tool6: Plan Review, BMP Construction, and Maintenance Checklists)

Inspectors should check to ensure that:

- Flows through the Filter Strip do not short-circuit the overflow control section;
- Debris and sediment does not build up at the top of the Filter Strip;
- Foot or vehicular traffic does not compromise the gravel diaphragm;
- Scour and erosion do not occur within the Filter Strip;
- Sediments are cleaned out of Level Spreader forebays and flow splitters; and
- Vegetative density exceeds a 90% cover in the boundary zone or grass filter.

9.3. Ongoing Maintenance

Once established, Vegetated Filter Strips have minimal maintenance needs outside of the spring clean up, regular mowing, repair of check dams and other measures to maintain the hydraulic efficiency of the strip and a dense, healthy grass cover. Vegetated Filter Strips that consist of grass/turf cover should be mowed at least twice a year to prevent woody growth.

SECTION 10. REFERENCES

Cappiella, K., T. Schueler, and T. Wright. 2006. *Urban Watershed Forestry Manual, Part 2. Conserving and Planting Trees at Development Sites*. Center for Watershed Protection. Prepared for United States Department of Agriculture, Forest Service.

City of Portland, Environmental Services. 2004. *Portland Stormwater Management Manual*. Portland, OR. Available online at: http://www.portlandonline.com/bes/index.cfm?c=dfbbh

Claytor, R. and T. Schueler. 1996. *Design of Stormwater Filtering Systems*. Center for Watershed Protection. Ellicott City, MD.

CWP. 2007. *National Pollutant Removal Performance Database Version 3.0*. Center for Watershed Protection, Ellicott City, MD.

Hathaway, J. and B. Hunt. 2006. *Level Spreaders: Overview, Design, and Maintenance*. Department of Biological and Agricultural Engineering. NC State University. Raliegh, NC. http://www.bae.ncsu.edu/stormwater/PublicationFiles/LevelSpreaders2006.pdf.

Henrico County, Virginia. *Henrico County Environmental Program Manual*. Available online at: http://www.co.henrico.va.us/works/eesd/

North Carolina State University. *Level Spreader Design Worksheet*. Available online at: http://www.bae.ncsu.edu/cont_ed/main/handouts/lsworksheet.pdf

North Carolina Department of Environment and Natural Resources, Division of Water Quality. "Level Spreader Design Guidelines." January 2007. Available online at: http://h2o.enr.state.nc.us/su/Manuals_Factsheets.htm

Northern Virginia Regional Commission. 2007. *Low Impact Development Supplement to the Northern Virginia BMP Handbook*. Fairfax, Virginia.

Philadelphia Stormwater Management Guidance Manual. Available online at: http://www.phillyriverinfo.org/Programs/SubprogramMain.aspx?Id=StormwaterManual

Schueler, T., D. Hirschman, M. Novotney and J. Zielinski. 2007. *Urban Stormwater Retrofit Practices*. Manual 3 in the Urban Subwatershed Restoration Manual Series. Center for Watershed Protection, Ellicott City, MD.

Schueler, T. 2008. Technical Support for the Baywide Runoff Reduction Method. Chesapeake Stormwater Network. Baltimore, MD. www.chesapeakestormwater.net

Virginia Stormwater Management Handbook. 1999. *Volumes 1 and 2*. Richmond, VA.

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 3

GRASS CHANNELS

VERSION 1.9
March 1, 2011

SECTION 1: DESCRIPTION

Grass channels can provide a modest amount of runoff filtering and volume attenuation within the stormwater conveyance system resulting in the delivery of less runoff and pollutants than a traditional system of curb and gutter, storm drain inlets and pipes. The performance of grass channels will vary depending on the underlying soil permeability (Table 1). Grass channels, however, are not capable of providing the same stormwater functions as dry swales as they lack the storage volume associated with the engineered soil media (see Specification No. 10). Their runoff reduction performance can be boosted when compost amendments are added to the bottom of the swale (See Stormwater Design Specification No. 4). Grass channels are a preferable alternative to both curb and gutter and storm drains as a stormwater conveyance system, where development density, topography and soils permit. Grass channels can also be used to treat runoff from the managed turf areas of turf-intensive land uses, such as sports fields and golf courses, and drainage areas with combined impervious and turf cover (e.g., roads and yards).

SECTION 2: PERFORMANCE

Table 3.1. Summary of Stormwater Functions Provided by Grass Channels [1]

Stormwater Function	HSG Soils A and B		HSG Soils C and D	
	No CA [2]	**With CA**	**No CA**	**With CA**
Annual Runoff Volume Reduction (RR)	20%	NA [3]	10%	30%
Total Phosphorus (TP) EMC Reduction[4] by BMP Treatment Process	15%		15%	
Total Phosphorus (TP) Mass Load Removal	32%		24% (no CA) to 41% (with CA)	
Total Nitrogen (TN) EMC Reduction[4] by BMP Treatment Process	20%		20%	
Total Nitrogen (TN) Mass Load Removal	36%		28% (no CA) to 44% (with CA)	
Channel & Flood Protection	**Partial.** Designers can use the RRM spreadsheet to adjust curve number for each design storm for the contributing drainage area, based on annual runoff reduction achieved. Also, the Tc for the grass swale flow path should reflect the slope and appropriate roughness for the intended vegetative cover.			

[1] CWP and CSN (2008) and CWP (2007).
[2] CA= Compost Amended Soils, see Stormwater Design Specification No. 4.
[3] Compost amendments are generally not applicable for A and B soils, although it may be advisable to incorporate them on mass-graded and/or excavated soils to maintain runoff reduction rates. In these cases, the 30% runoff reduction rate may be claimed, regardless of the pre-construction HSG.
[4] Change in event mean concentration (EMC) through the practice. Actual nutrient mass load removed is the product of the pollutant removal rate and the runoff volume reduction rate (see Table 1 in the *Introduction to the New Virginia Stormwater Design Specifications*).

SECTION 3: DESIGN TABLE

Grass channels only have *one* level of design, and must meet the minimum criteria outlined in **Table 3.2** to qualify for the indicated level of runoff reduction.

Table 3.2. Grass Channel Design Guidance

Design Criteria
The bottom width of the channel should be between 4 to 8 feet wide.
The channel side-slopes should be 3H:1V or flatter.
The maximum total contributing drainage area to any individual grass channel is 5 acres.
The longitudinal slope of the channel should be no greater than 4%. (Check dams may be used to reduce the effective slope in order to meet the limiting velocity requirements.)
The maximum flow velocity of the channel must be less than 1 foot per second during a 1-inch storm event.
The dimensions of the channel should ensure that flow velocity is non-erosive during the 2-year and 10-year design storm events and the 10-year design flow is contained within the channel (minimum of 6 inches of freeboard).

SECTION 4: TYPICAL DETAILS

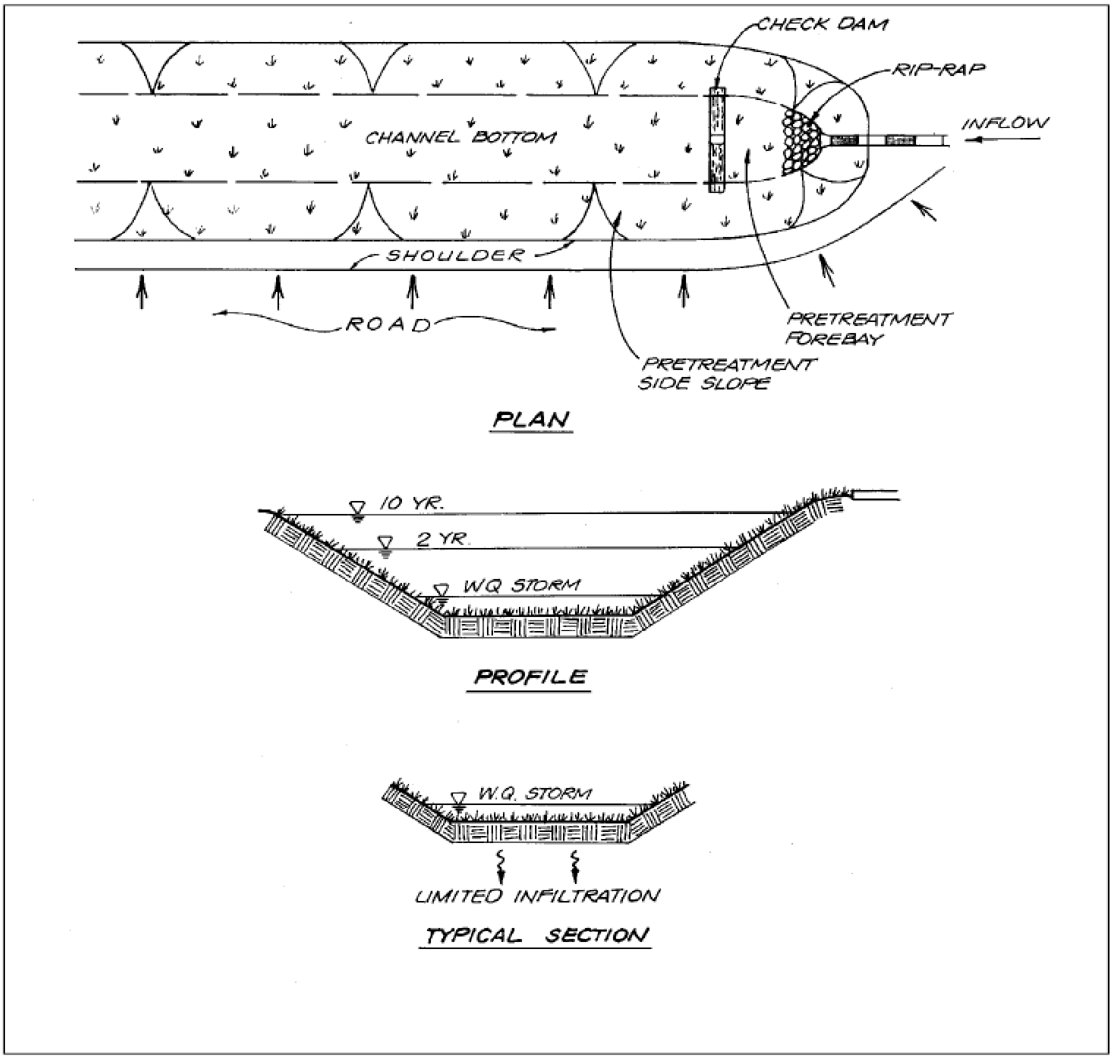
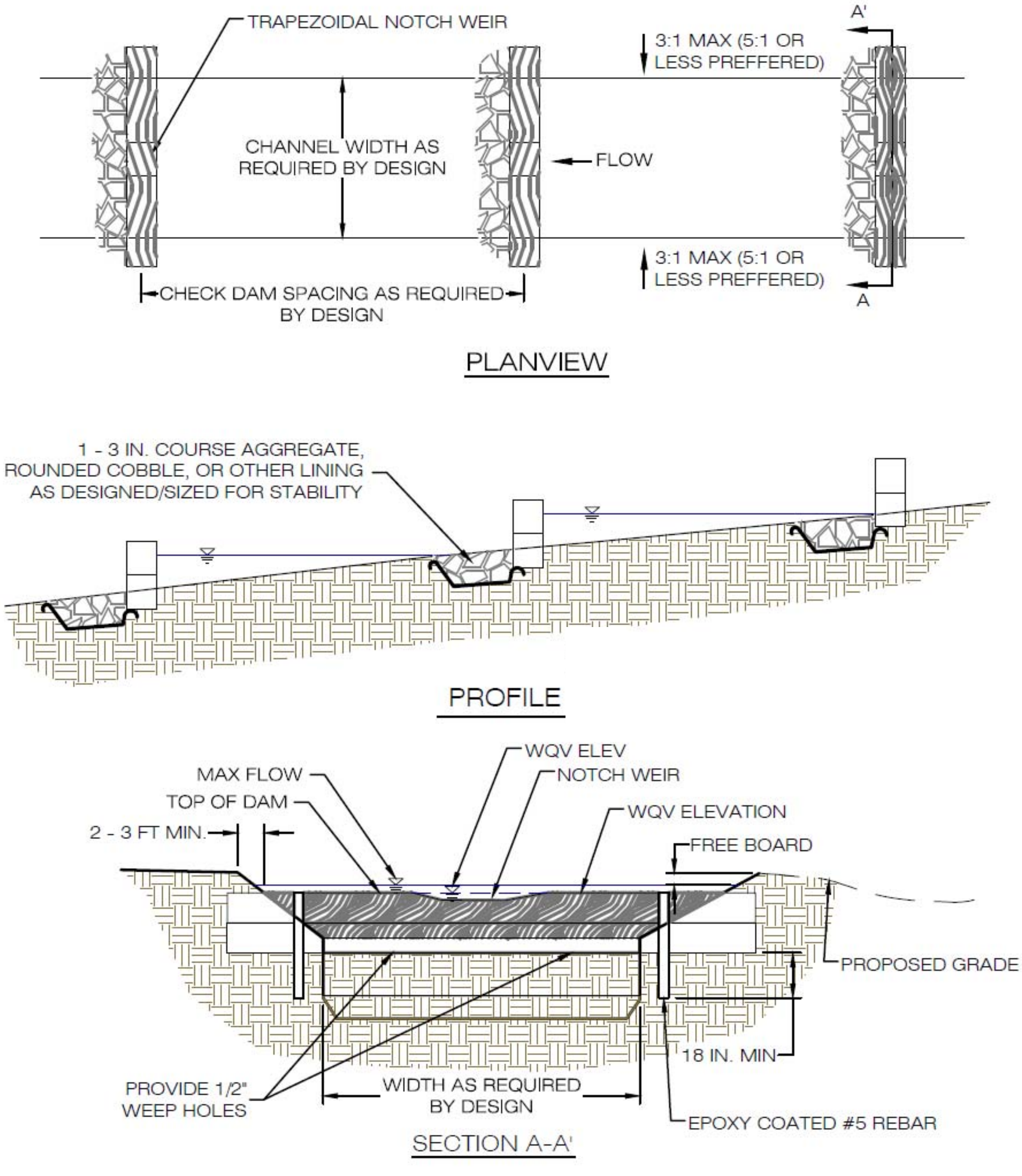


Figure 3.1. Grass Channel – Typical Plan, Profile and Section



NOTE: CHECK DAM CONSTRUCTED OF RAILROAD TIES, PRESSURE TREATED LOGS OR TIMBERS, OR CONCRETE.

Figure 3.2 Grass Channel with Check Dams – Typical Plan, Profile, and Section

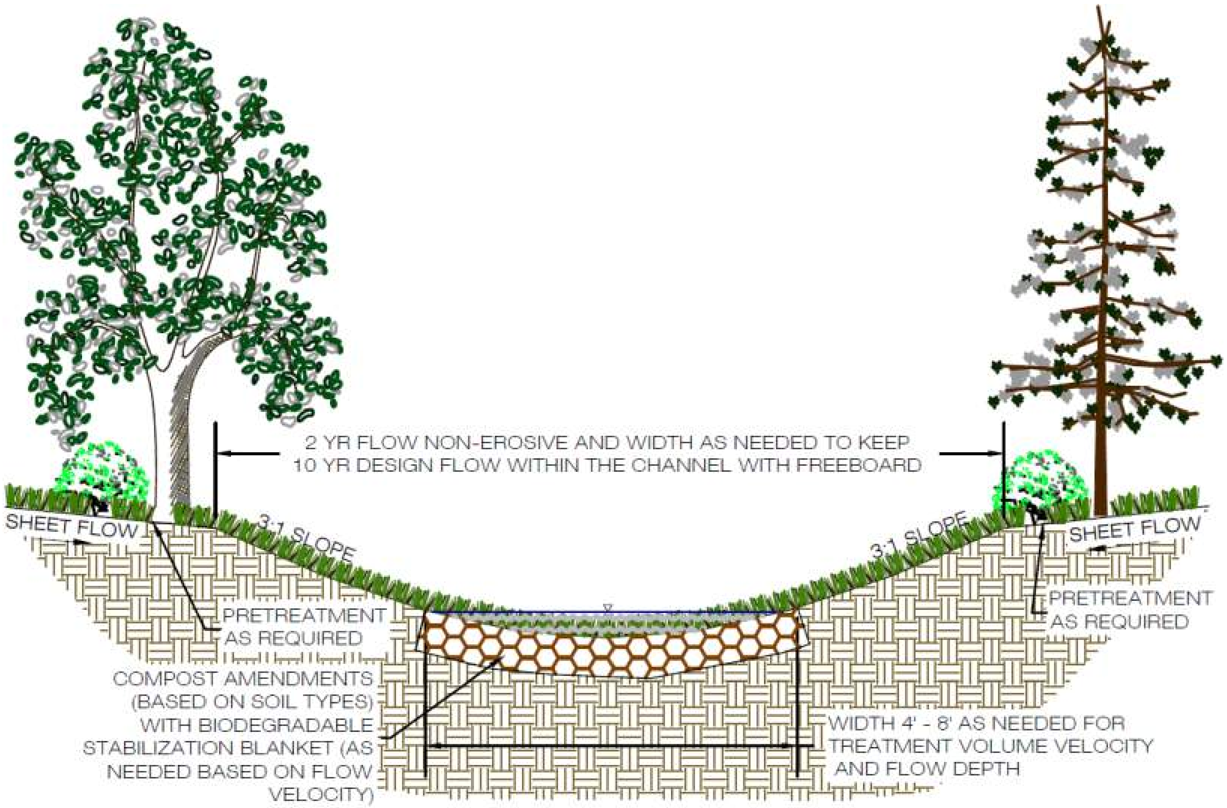


Figure 3.3: Grass Channel with Compost Amendments - Section

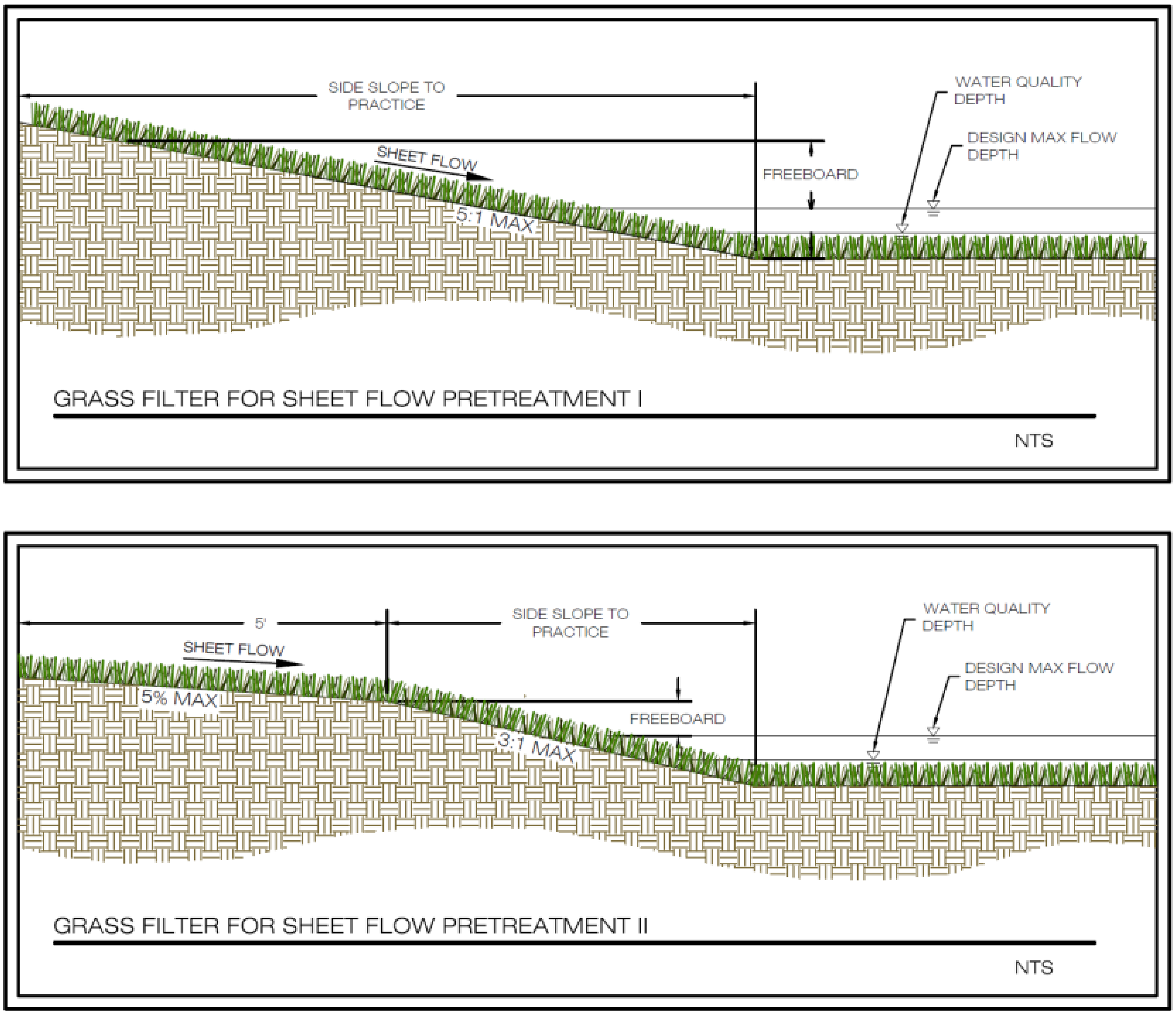


Figure 3.4: Pretreatment I and II - Grass Filter for Sheet Flow

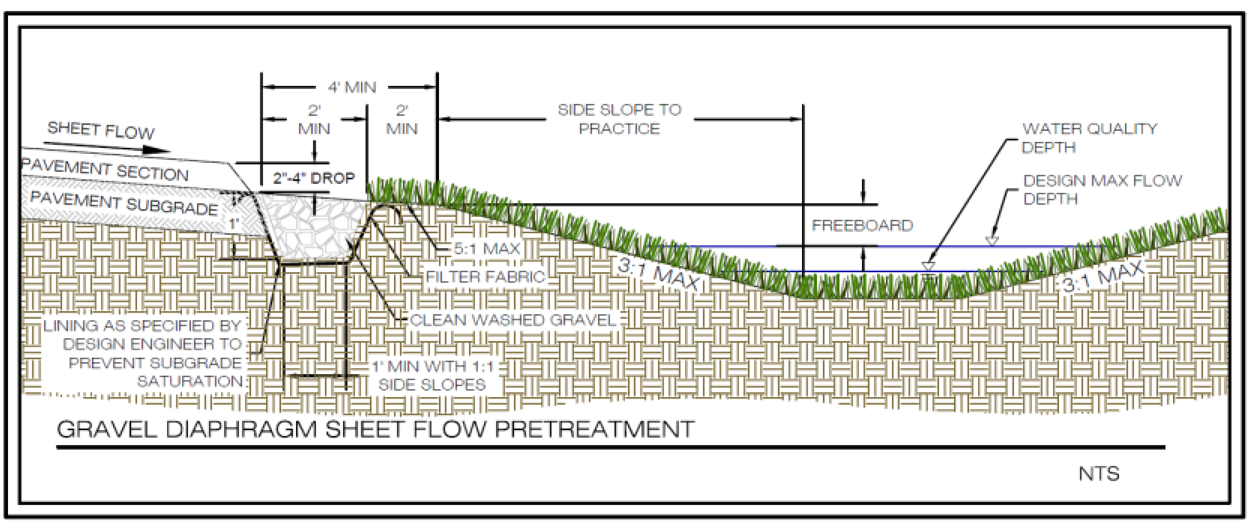


Figure 3.5: Pretreatment – Gravel Diaphragm for Sheet Flow from Impervious or Pervious

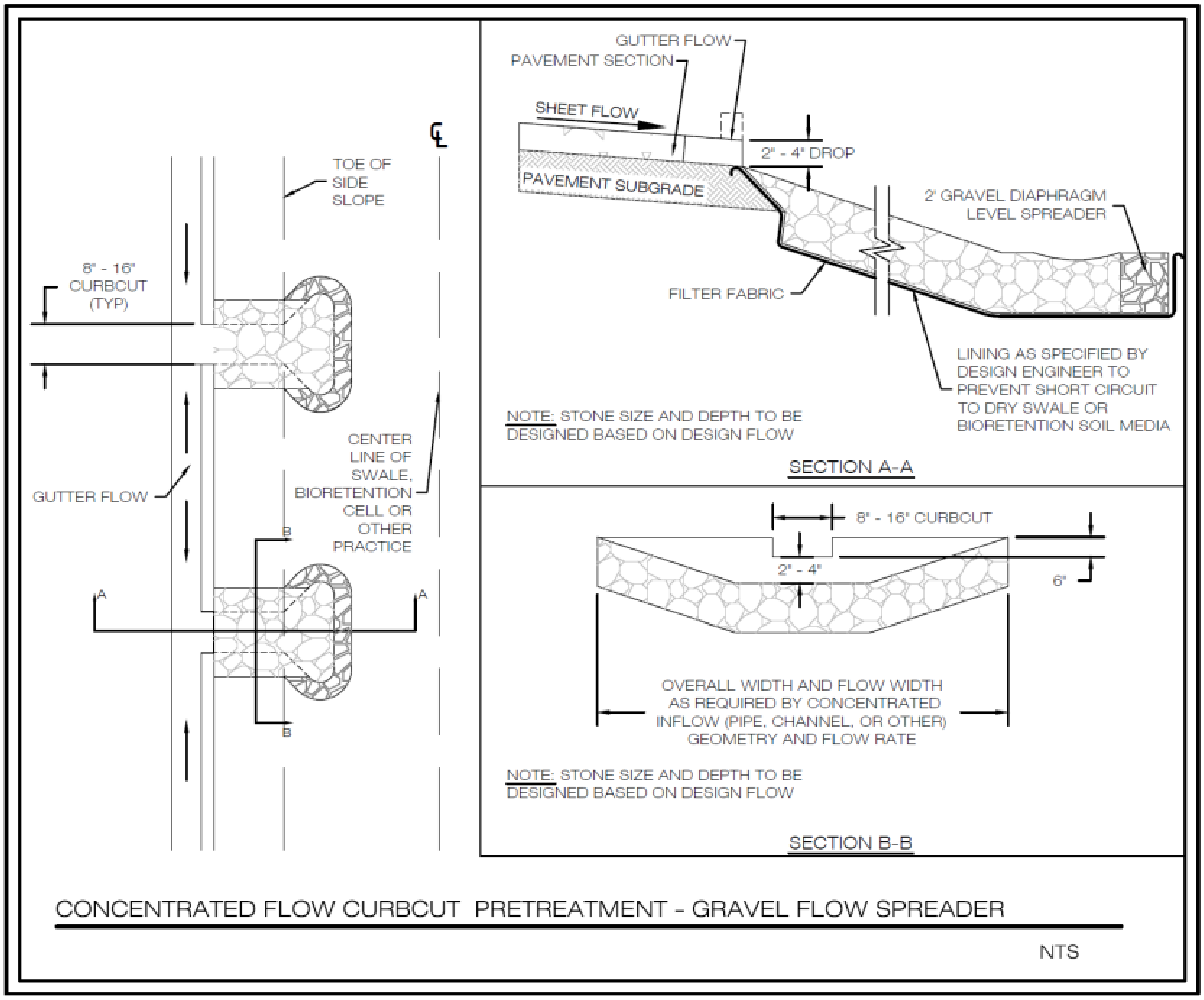


Figure 3.6: Pre-Treatment – Gravel Flow Spreader for Concentrated Flow

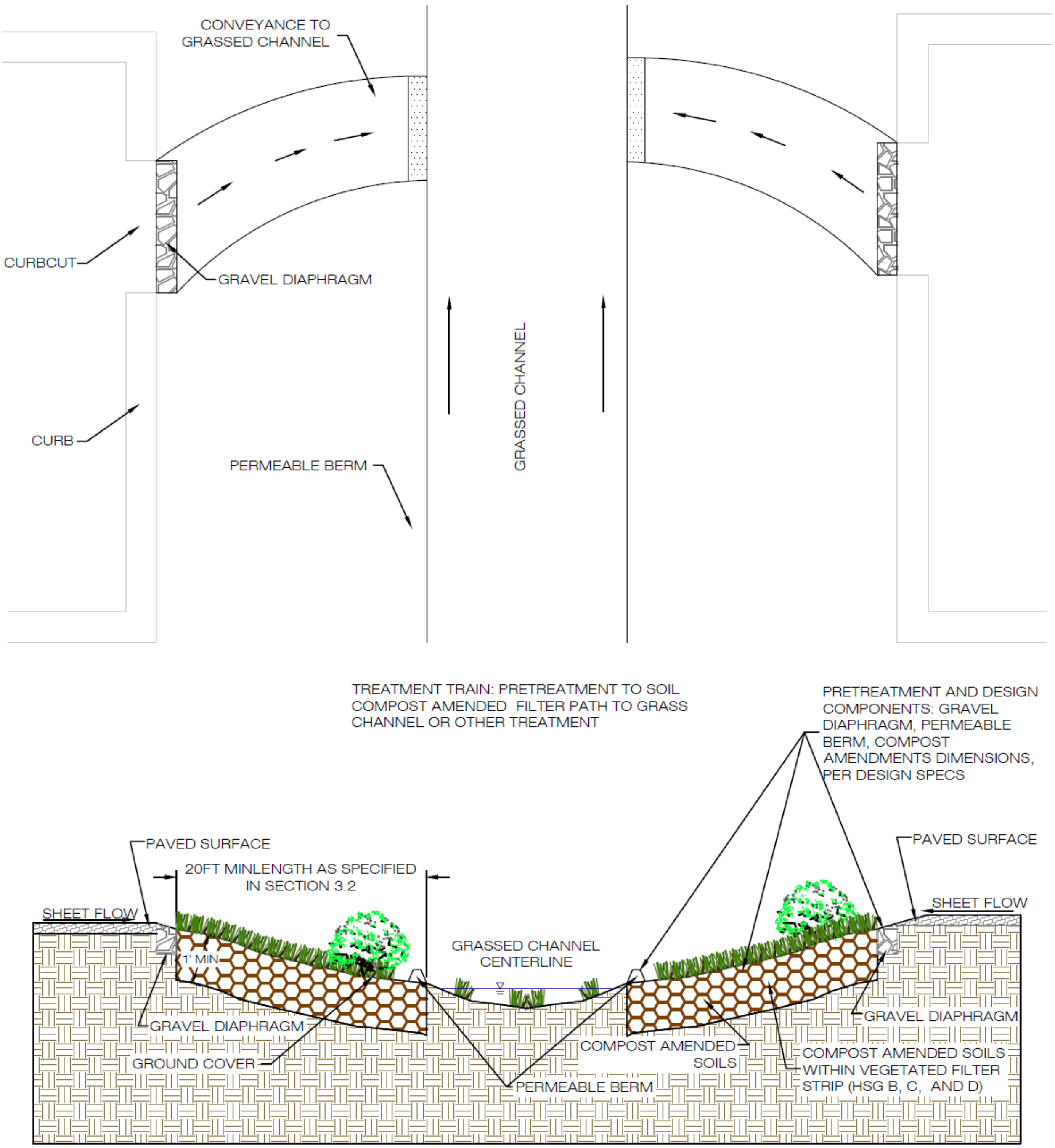


Figure 3.7: Filter Path to Grass Channel

SECTION 5: PHYSICAL FEASIBILITY AND DESIGN APPLICATIONS

Grass channels can be implemented on suitable development sites where development density, topography and soils are suitable. The linear nature of grass channels makes them well-suited to treat highway runoff, low and medium density residential road and yard runoff (if there is an adequate right-of-way width and distance between driveways), and small commercial parking areas or driveways. However, a Dry Swale (Design Specification 10) will provide much greater runoff reduction and pollutant removal performance.

Grass channels are not recommended when residential density exceeds more than 4 dwelling units per acre, due to a lack of available land and the frequency of driveway crossings along the channel. Grass channels can also provide pre-treatment for other stormwater treatment practices.

Key constraints for grass channels include:

Land Uses. Grass channels can be used in residential, commercial, or institutional development settings. However, when grass channels are used for both conveyance and water quality treatment, they should be applied only in linear configurations parallel to the contributing impervious cover, such as roads and small parking areas.

- Residential uses are typically limited to densities of 4 dwelling units per acre in order to avoid safety and nuisance conditions.
- Large commercial site applications may require multiple channels in order to effectively break up the drainage areas and meet the design criteria.
- The linear nature of grass channels makes them well suited to treat highway or low- and medium-density residential road runoff, if there is adequate right-of-way width and distance between driveways.
- Grass channels can be used to treat the managed turf areas of sports fields, golf courses, and other turf-intensive land uses, or to treat drainage areas with both impervious and managed turf cover (such as residential streets and yards), as long as drainage area limitations and design criteria can be met.

Contributing Drainage Area. The maximum contributing drainage area to a grass channel should be 5 acres, and preferably less. When grass channels treat and convey runoff from drainage areas greater than 5 acres, the velocity and flow depth through the channel becomes too great to treat runoff or prevent erosion in the channel. The design criteria for maximum channel velocity and depth are applied along the entire length, and must meet regulatory requirements (4 VAC 50-60-66) at the downstream limit.

Available Space. Grass channels can be incorporated into linear development applications (e.g., roadways) by utilizing the footprint typically required for an open section drainage feature. The footprint required will likely be greater than that of a typical conveyance channel (VDOT or equivalent). However, the benefit of the runoff reduction may reduce the footprint requirements for stormwater management elsewhere on the development site.

Longitudinal Slope. Grass channels are limited to longitudinal slopes of less than 4%. However, the limiting velocity requirements will typically require check dams to reduce the effective slope. Slopes steeper than 4% create rapid runoff velocities that can cause erosion and do not allow enough contact time for infiltration or filtering, unless check dams are used.

Longitudinal slopes of less than 2% are ideal and may eliminate the need for check dams. However, channels designed with longitudinal slopes of less than 1% should be monitored carefully during construction to ensure a continuous grade, in order to avoid flat areas with pockets of standing water.

Soils. Grass channels can be used on sites with any type of soils. However, grass channels situated on Hydrologic Soil Group C and D soils will require compost amendments in order to improve performance, as noted in **Table 3.1** (see Stormwater Design Specification No. 4).

Hydraulic Capacity. Grass channels are an on-line practice and must be designed with enough capacity to convey runoff from the 10-year design storm event within the channel banks and be non-erosive during both the 2-year and 10-year design storm events. This means that the much of the surface dimensions are driven by the need to pass these larger storm events.

Depth to Water Table. Designers should ensure that the bottom of the grass channel is at least 2 feet above the seasonally high water table to ensure groundwater does not intersect the filter bed, because this could lead to groundwater contamination or practice failure.

Utilities. Designers should consult local utility design guidance for the horizontal and vertical clearance between utilities and the channels. Typically, utilities can cross grass channels if they are specially protected (e.g., double-casing) or are located below the channel invert.

Hotspot Land Uses. Grass channels are not recommended to treat stormwater hotspots, due to the potential for infiltration of hydrocarbons, trace metals and other toxic pollutants into groundwater. For a list of typical stormwater hotspots, see Stormwater Design Specification No. 8 (Infiltration).

Minimum Setbacks. Local ordinances and design criteria should be consulted to determine minimum setbacks from property lines, structures, utilities, and wells. As a general rule, grass channels should be set back at least 10 feet down-gradient from building foundations, 50 feet from septic system fields and 100 feet from private wells.

SECTION 6: DESIGN CRITERIA

6.1. Sizing of Grass Channels

Unlike other stormwater practices, grass channels are designed based on a peak rate of flow. Designers must demonstrate channel conveyance and treatment capacity in accordance with the following guidelines:

- The longitudinal slope of the channel should ideally be between 1% and 2% in order to avoid scour and short-circuiting within the channel. Longitudinal slopes up to 4% are acceptable; however, check dams will likely be required in order to meet the allowable maximum flow velocities.
- Hydraulic capacity should be verified using Manning's Equation or an accepted equivalent method, such as erodibility factors and vegetal retardance (NOVA 2007).
  - The Flow Depth for the peak treatment volume (1-inch rainfall) should be maintained at 3 inches or less.
  - Manning's "n" value for grass channels should be 0.2 for flow depths up to 4 inches, decreasing to 0.03 at a depth of 12 inches (which would apply to the 2-year and 10-year storms if an on-line application – NOVA, 2007; Haan et. al, 1994).
  - Peak Flow Rates for the 2-year and 10-year frequency storms must be non-erosive, in accordance with **Table 3.3**, or subject to a site-specific analysis of the channel lining material and vegetation; and the 10-year peak flow rate must be contained within the channel banks (with a minimum of 6 inches of freeboard). (NOTE: After the new Virginia Stormwater Management Regulation revisions take effect, the above requirement will be driven by the SWM Regulations (4 VAC 50-60-66 A 1 and B 1), which will supersede the MS-19 criteria of the Virginia E&S Control Regulations.)

- Calculations for peak flow depth and velocity should reflect any increase in flow along the length of the channel, as appropriate. If a single flow is used, the flow at the outlet should be used.
- The hydraulic residence time (the time for runoff to travel the full length of the channel) should be a minimum of 9 minutes for the treatment volume (1-inch rainfall) design storm (Spyridakis, Mar, and Horner, 1982; Keblin, Walsh, Malina, and Charbeneau, 1998; Washington State Department of Ecology, 2005). If flow enters the swale at several locations, a 9 minute minimum hydraulic residence time should be demonstrated for each entry point, using Equations 3.1 and 3.2 below (Equations 5-1 and 5-2, NOVA 2007).
- The minimum length may be achieved with multiple swale segments connected by culverts with energy dissipaters.

The bottom width of the grass channel is therefore sized to maintain the appropriate flow geometry as follows:

Equation 3.1: Manning's Equation

$$V = \left[\left(\frac{1.49}{n}\right)D^{2/3}s^{1/2}\right]$$

Where:

V = flow velocity (ft./sec.)
n = roughness coefficient (0.2, or as appropriate)
D = flow depth (ft.) (NOTE: D approximates hydraulic radius for shallow flows)
s = channel slope (ft./ft.)

Equation 3.2: Continuity Equation

$$Q = V(WD)$$

Where:

Q = design Treatment Volume flow (cfs)
V = design flow velocity (ft./sec.)
W = channel width (ft.)
D = flow depth (ft.)
(NOTE: channel width (W) x depth (D) approximates the cross sectional flow area for shallow flows.)

Combining Equations 3.1 and 3.2, and re-writing them provides a solution for the minimum width:

Equation 3.3: Minimum Width

$$W = {(nQ)}/{(1.49D^{5/3}s^{1/2})}$$

Solving Equation 3.2 for the corresponding velocity provides:

Equation 3.4: Corresponding Velocity

$$V = Q\ /\ WD$$

The resulting velocity should be less than 1 ft./sec. The width, slope, or Manning's "*n*" value can be adjusted to provide an appropriate channel design for the site conditions. However, if a higher density of grass is used to increase the Manning's "*n*" value and decrease the resulting channel width, it is important to provide material specifications and construction oversight to ensure that the denser vegetation is actually established. Equation 3.5 can then be used to ensure adequate hydraulic residence time.

Equation 3.5: Grass Channel Length for Hydraulic Residence Time of 9 minutes (540 seconds)

$$L = 540V$$

Where:

L = minimum swale length (ft.)
V = flow velocity (ft./sec.)

Table 3.3: Maximum Permissible Velocities for Grass Channels

Cover Type	Slope (%)	Erosion Resistant Soils (ft./sec.)	Easily Eroded Soils (ft./sec.)
Bermudagrass	0 – 5	6	4.5
Kentucky bluegrass Reed canarygrass Tall fescue	0 – 5	5	3.8
Bermudagrass	5 – 10	5	3.8
Kentucky bluegrass Reed canarygrass Tall fescue	5 – 10	4	3
Grass-legume mixture	0 – 5 5 - 10	4 3	3 2.3
Kentucky bluegrass Reed canarygrass Tall fescue	> 10	3	2.3
Red fescue	0 - 5	2.5	1.9

Sources: Virginia E&S Control Handbook, 1992; Ree, 1949; Temple et al, 1987; NOVA, 2007

6.2. Geometry and Site Layout

- Grass channels should generally be aligned adjacent to and the same length (minimum) as the contributing drainage area identified for treatment.
- Grass channels should be designed with a trapezoidal or parabolic cross section. A parabolic shape is preferred for aesthetic, maintenance and hydraulic reasons.
- The bottom width of the channel should be between 4 to 8 feet wide. If a channel will be wider than 8 feet, the designer should incorporate benches, check dams, level spreaders or multi-level cross sections to prevent braiding and erosion along the channel bottom.
- Grass channel side slopes should be no steeper than 4H:1V for ease of mowing and routine maintenance. Flatter slopes are encouraged, where adequate space is available, to aid in pre-treatment of sheet flows entering the channel. Under no circumstances are side slopes to exceed 3H:1V.

6.3. Pretreatment

Pretreatment is recommended for grass channels to dissipate energy, trap sediments and slow down the runoff velocity. The selection of a pre-treatment method depends on whether the channel will experience sheet flow or concentrated flow. Several reliable options are as follows:

- ***Check dams*** (channel flow): The most common form of pre-treatment is the use of wooden or stone check dams (see Section 6.7).
- ***Tree Check dams*** (channel flow): These are street tree mounds that are placed within the bottom of grass channels up to an elevation of 9 to 12 inches above the channel invert. One side has a gravel or river stone bypass to allow runoff to percolate through (Cappiella et al, 2006).
- ***Grass Filter Strip*** (sheet flow): Grass filter strips extend from the edge of the pavement to the bottom of the grass channel at a slope of 5:1 or less. Alternatively, provide a combined 5

feet of grass filter strip at a maximum 5% (20:1) cross slope and 3:1 or flatter side slopes on the grass channel.

- ***Gravel or Stone Diaphragm*** (sheet flow): The gravel diaphragm is located at the edge of the pavement or the edge of the roadway shoulder and extends the length of the channel to pre-treat lateral runoff. This requires a 2 to 4 inch elevation drop from a hard-edged surface into a gravel or stone diaphragm.
- ***Gravel or Stone Flow Spreaders*** (concentrated flow). The gravel flow spreader is located at curb cuts, downspouts, or other concentrated inflow points, and should have a 2 to 4 inch elevation drop from a hard-edged surface into a gravel or stone diaphragm. The gravel should extend the entire width of the opening and create a level stone weir at the bottom or treatment elevation of the channel.

6.4. Check dams

Check dams may be used for pre-treatment, to break up slopes, and to increase the hydraulic residence time in the channel. Design requirements for check dams are as follows:

- Check dams should be spaced based on the channel slope, as needed to increase residence time, provide T_v storage volume, or any additional volume attenuation requirements. The ponded water at a downhill check dam should not touch the toe of the upstream checkdam.
- The maximum desired check dam height is 12 inches (for maintenance purposes). However, for challenging sites, a maximum of 18 inches can be allowed, with additional design elements to ensure the stability of the check dam and the adjacent and underlying soils The average ponding depth throughout the channel should be 12 inches.
- Soil plugs serve to help minimize the potential for blow-out of the soil media underneath the check dams, due to hydrostatic pressure from the upstream ponding. Soil plugs are appropriate for Grass Channels (1) on slopes of 4% or greater, or (2) with check dams equal to or greater than 12-inches in height.
- Armoring may be needed at the downstream toe of the check dam to prevent erosion.
- Check dams must be firmly anchored into the side-slopes to prevent outflanking; check dams must also be anchored into the channel bottom so as to prevent hydrostatic head from pushing out the underlying soils.
- Check dams must be designed with a center weir sized to pass the channel design storm peak flow (10-year storm event for man-made channels).
- The check dam should be designed so that it facilitates easy mowing.
- Each check dam should have a weep hole or similar drainage feature so it can dewater after storms.
- Check dams should be composed of wood, concrete, stone, or other non-erodible material, or be should configured with elevated driveway culverts.
- Individual channel segments formed by check dams or driveways should generally be at least 25 to 40 feet in length.

6.5. Compost Soil Amendments

Soil compost amendments serve to increase the runoff reduction capability of a grass channel. The following design criteria apply when compost amendments are used:

- The compost-amended strip should extend over the length and width of the channel bottom, and the compost should be incorporated to a depth as outlined in Stormwater Design Specification No. 4.
- The amended area will need to be rapidly stabilized with perennial, salt tolerant grass species.
- For grass channels on steep slopes, it may be necessary to install a protective biodegradable geotextile fabric to protect the compost-amended soils. Care must be taken to consider the erosive characteristics of the amended soils when selecting an appropriate geotextile.
- For redevelopment or retrofit applications, the final elevation of the grass channel (following compost amendment) must be verified as meeting the original design hydraulic capacity.

6.6. Planting Grass Channels

Designers should choose grass species that can withstand both wet and dry periods as well as relatively high-velocity flows within the channel. For applications along roads and parking lots, salt tolerant species should be chosen. Taller and denser grasses are preferable, though the species of grass is less important than good stabilization. For a list of grass species suitable for use in grass channels, consult the Virginia Erosion Control Handbook.

Grass channels should be seeded at such a density to achieve a 90 % turf cover after the second growing season. Grass channels should be seeded and not sodded. Seeding establishes deeper roots and sod may have muck soil that is not conducive to infiltration (Wisconsin DNR, 2007). Grass channels should be protected by a biodegradable erosion control fabric to provide immediate stabilization of the channel bed and banks.

6.7. Grass Channel Material Specifications

The basic material specifications for grass channels are outlined in **Table 3.4** below.

Table 3.4. Grass Channel Materials Specifications

Component	Specification
Grass	A dense cover of water-tolerant, erosion-resistant grass. The selection of an appropriate species or mixture of species is based on several factors including climate, soil type, topography, and sun or shade tolerance. Grass species should have the following characteristics: a deep root system to resist scouring; a high stem density with well-branched top growth; water-tolerance; resistance to being flattened by runoff; an ability to recover growth following inundation; and, if receiving runoff from roadways, salt-tolerance.
Check Dams	• Check dams should be constructed of a non-erosive material such as wood, gabions, riprap, or concrete. All check dams should be underlain with filter fabric conforming to local design standards. • Wood used for check dams should consist of pressure treated logs or timbers, or water-resistant tree species such as cedar, hemlock, swamp oak or locust. • Computation of check dam material is necessary, based on the surface area and depth used in the design computations.(see Appendix A of this design specification).
Diaphragm	Pea gravel used to construct pre-treatment diaphragms should consist of washed, open-graded, course aggregate between 3 and 10 mm in diameter and must conform to local design standards.
Erosion Control Fabric	Where flow velocities dictate, biodegradable erosion control netting or mats that are durable enough to last at least two growing seasons must be used, conforming to Standard and Specification 3.36 of the Virginia Erosion and Sediment Control Handbook.
Filter Fabric (check dams)	Needled, non-woven, polypropylene geotextile meeting the following specifications: Grab Tensile Strength (ASTM D4632): $\geq$ 120 lbs Mullen Burst Strength (ASTM D3786): $\geq$ 225 lbs./sq. in. Flow Rate (ASTM D4491): $\geq$ 125 gpm/sq. ft. Apparent Opening Size (ASTM D4751): US #70 or #80 sieve

SECTION 7: REGIONAL & SPECIAL CASE DESIGN ADAPTATIONS

7.1. Karst Terrain

Grass channels are an acceptable practice in karst terrain, as long as they do not treat hotspot runoff. The following design adaptations apply to grass channels in karst terrain:

- Soil compost amendments may be incorporated into the bottom of grass channels to improve their runoff reduction capability, as noted in **Table 3.1** above.
- Check dams are generally discouraged for grass swales in karst terrain, since they pond too much water (although flow spreaders that are flush with the ground surface and spaced along the channel length may be useful in spreading flows more evenly across the channel width).
- The minimum depth to the bedrock layer is 18 inches.
- A minimum slope of 0.5% must be maintained to ensure positive drainage.
- The grass channel may have off-line cells and should be tied into an adequate discharge point.

7.2. Coastal Plain

Although grass channels work reasonably well in the flat terrain and low head conditions of many coastal plain sites, they have very poor nutrient and bacteria removal rates, and should not be used as a stand-alone treatment system. Dry swales or wet swales are much superior options to the grass channel, unless the soils are in the highly permeable HSG "A" group. Where HSG-A soils occur:

- The minimum depth from the swale invert to the seasonally high water table should be 12 inches.
- A minimum slope of 0.5% must be maintained to ensure positive drainage.
- The grass channel may have off-line cells and should be tied into the ditch system

7.3. Steep Terrain

Grass swales are not practical in areas of steep terrain, although terracing a series of grass swale cells may work on slopes from 5% to 10%. The drop in elevation between check dams should be limited to 18 inches in these cases, and the check dams should be armored on the down-slope side with suitably sized stone to prevent erosion.

7.4. Cold Climate and Winter Performance

Grass swales can store snow and treat snowmelt runoff when they serve road or parking lot drainage. If roadway salt is applied in their CDA, grass swales should be planted with salt-tolerant species. Consult the Minnesota Stormwater Manual for a list of salt-tolerant grass species (MSSC, 2005).

7.5. Linear Highway Sites

Grass swales are a preferred stormwater practice for linear highway sites.

SECTION 8: CONSTRUCTION

8.1. Construction Sequence

The following is a typical construction sequence to properly install a grass channel, although steps may be modified to reflect different site conditions. Grass channels should be installed at a time of year that is best to establish turf cover without irrigation. Some local agencies restrict planting to the following periods of time: February 15 through April 15 and September 15 through November 15.

Step 1: Protection during Site Construction. Ideally, grass channels should remain outside the limit of disturbance during construction to prevent soil compaction by heavy equipment. However, this is seldom practical, given that the channels are a key part of the drainage system at most sites. In these cases, temporary E&S controls such as dikes, silt fences and other erosion control measures should be integrated into the swale design throughout the construction sequence. Specifically, barriers should be installed at key check dam locations, and erosion control fabric shoud be used to protect the channel.

Step 2. Grass channel installation may only begin after the entire contributing drainage area has been stabilized with vegetation. Any accumulation of sediments that does occur within the channel must be removed during the final stages of grading to achieve the design cross-section. Erosion and sediment controls for construction of the grass channel should be installed as specified in the erosion and sediment control plan. Stormwater flows must not be permitted into the grass channel until the bottom and side slopes are fully stabilized.

Step 3. Grade the grass channel to the final dimensions shown on the plan.

Step 4. Install check dams, driveway culverts and internal pre-treatment features as shown on the plan. Fill material used to construct check dams should be placed in 8- to 12-inch lifts and compacted to prevent settlement. The top of each check dam should be constructed level at the design elevation.

Step 5 (Optional). Till the bottom of the channel to a depth of 1 foot and incorporate compost amendments according to Stormwater Design Specification No. 4.

Step 6. Add soil amendments as needed, hydro-seed the bottom and banks of the grass channel, and peg in erosion control fabric or blanket where needed. After initial planting, a biodegradable erosion control fabric should be used, conforming to Standard and Specification 3.36 of the Virginia Erosion and Sediment Control Handbook.

St*ep 7.* Prepare planting holes for any trees and shrubs, then plant materials as shown in the landscaping plan and water them weekly in the first two months. The construction contract should include a Care and Replacement Warranty to ensure vegetation is properly established and survives during the first growing season following construction.

Step 8. Conduct the final construction inspection and develop a punchlist for facility acceptance.

8.2 Construction Inspection

Inspections during construction are needed to ensure that the grass channel is built in accordance with these specifications. An example construction phase inspection checklist for Grass Channels can be accessed at the Center for Watershed Protection website at:

http://www.cwp.org/Resource_Library/Controlling_Runoff_and_Discharges/sm.htm
(scroll to Tool6: Plan Review, BMP Construction, and Maintenance Checklists)

Some common pitfalls can be avoided by careful post-storm inspection of the grass channel:

- Make sure the desired coverage of turf or erosion control fabric has been achieved following construction, both on the channel beds and their contributing side-slopes.

- Inspect check dams and pre-treatment structures to make sure they are at correct elevations, are properly installed, and are working effectively.
- Make sure outfall protection/energy dissipation at concentrated inflows are stable.

The real test of a grass swale occurs after its first big storm. Minor adjustments are normally needed as part of this post-storm inspection (e.g., spot reseeding, gully repair, added armoring at inlets, or realignment of outfalls and check dams).

SECTION 9: MAINTENANCE

9.1 Maintenance Agreements

Section 4 VAC 50-60-124 of the regulations specifies the circumstances under which a maintenance agreement must be executed between the owner and the local program. This section sets forth inspection requirements, compliance procedures if maintenance is neglected, notification of the local program upon transfer of ownership, and right-of-entry for local program personnel.

All grass channels must be covered by a drainage easement to allow inspection and maintenance. If a grass channel is located in a residential private lot, the existence and purpose of the grass channel shall be noted on the deed of record. Homeowners will need to be provided a simple document that explains their purpose and routine maintenance needs. A deed restriction or other mechanism enforceable by the qualifying local program must be in place to help ensure that grass channels are maintained with proper line and grade. The mechanism should, if possible, grant authority for local agencies to access the property for inspection or corrective action.

9.2. Maintenance Inspections

Annual inspections are used to trigger maintenance operations such as sediment removal, spot re-vegetation and inlet stabilization. Several key maintenance inspection points are detailed in **Table 3.5**. Ideally, inspections should be conducted in the spring of each year. Example maintenance inspection checklists for Grass Channels can be accessed in Appendix C of Chapter 9 of the *Virginia Stormwater Management Handbook* (2010) or at the CWP website at:

http://www.cwp.org/Resource_Library/Controlling_Runoff_and_Discharges/sm.htm
(scroll to Tool6: Plan Review, BMP Construction, and Maintenance Checklists)

9.3. Ongoing Maintenance

Once established, grass channels have minimal maintenance needs outside of the spring clean up, regular mowing, repair of check dams and other measures to maintain the hydraulic efficiency of the channel and a dense, healthy grass cover.

Table 3.5. Suggested Spring Maintenance Inspections/Cleanups for Grass Channels

Activity
Add reinforcement planting to maintain 90% turf cover. Reseed any salt-killed vegetation.
Remove any accumulated sand or sediment deposits behind check dams.
Inspect upstream and downstream of check dams for evidence of undercutting or erosion, and remove and trash or blockages at weepholes.
Examine channel bottom for evidence of erosion, braiding, excessive ponding or dead grass.
Check inflow points for clogging and remove any sediment.
Inspect side slopes and grass filter strips for evidence of any rill or gully erosion and repair.
Look for any bare soil or sediment sources in the contributing drainage area and stabilize immediately.

SECTION 10: COMMUNITY AND ENVIRONMENTAL CONCERNS

The main concerns of adjacent residents are perceptions that grass channels will create nuisance conditions or will be hard to maintain. Common concerns include the continued ability to mow grass, landscape preferences, weeds, standing water, and mosquitoes. Dry swales are a much better alternative, creating fewer objections and achieving greater pollution removal.

SECTION 11: DESIGN REFERENCES

Claytor, R. and T. Schueler. 1996. *Design of Stormwater Filtering Systems*. Center for Watershed Protection. Ellicott City, MD.

CWP. 2007. *National Pollutant Removal Performance Database Version 3.0*. Center for Watershed Protection, Ellicott City, MD.

Haan, C.T., Barfield, B.J., and Hayes, J.C. *Design Hydrology and Sedimentology for Small Catchments*. Academic Press, New York, 1994.

Lantin, A., and M. Barrett. 2005. *Design and Pollutant Reduction of Vegetated Strips and Swales*. ASCE. Downloaded September, 2005.

Maryland Department of Environment (MDE). 2000. *Maryland Stormwater Design Manual*. Baltimore, MD. Available online at: http://www.mde.state.md.us/Programs/WaterPrograms/SedimentandStormwater/stormwater_design/index.asp

Northern Virginia Regional Commission. 2007. *Low Impact Development Supplement to the Northern Virginia BMP Handbook*. Fairfax, Virginia

Schueler, T., D. Hirschman, M. Novotney and J. Zielinski. 2007. *Urban Stormwater Retrofit Practices*. Manual 3 in the Urban Subwatershed Restoration Manual Series. Center for Watershed Protection, Ellicott City, MD.

Schueler, T. 2008. Technical Support for the Baywide Runoff Reduction Method. Chesapeake Stormwater Network. Baltimore, MD. www.chesapeakestormwater.net

Virginia Stormwater Management Handbook. 1999. *Volumes 1 and 2*. Richmond, VA.

Wisconsin Department of Natural Resources. "Vegetated Infiltration Swale (1005)." *Interim Technical Standard*, *Conservation Practice Standards*. Standards Oversight Council, Madison, Wisconsin, 2004. Available online at: http://dnr.wi.gov/org/water/wm/nps/pdf/stormwater/techstds/post/Interim_Infiltration_Swale_1005.pdf.

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 4

SOIL COMPOST AMENDMENT

VERSION 1.8
March 1, 2011

SECTION 1: DESCRIPTION

Soil restoration is an Environmental Site Design (ESD) practice applied after construction, to deeply till compacted soils and restore their porosity by amending them with compost. These soil amendments can reduce the generation of runoff from compacted urban lawns and may also be used to enhance the runoff reduction performance of downspout disconnections, grass channels, and filter strips (**Table 4.1**).

SECTION 2: PERFORMANCE

Table 4.1: Stormwater Functions of Soil Compost Amendments [1]

Stormwater Function	HSG Soils A and B		HSG Soils C and D	
	No CA [2]	With CA	No CA	With CA
Annual Runoff Volume Reduction (RR)				
Simple Rooftop Disconnection	**50%**	**NA** [3]	**25%**	**50%**
Filter Strip	**50%**	**NA** [3]	**NA** [4]	**50%**
Grass Channel	**20%**	**NA** [3]	**10%**	**30%**
Total Phosphorus (TP) EMC Reduction[4] **by BMP Treatment Practice**	**0**		**0**	
Total Phosphorus (TP) Mass Load Removal	**Same as for RR (above)**		**Same as for RR (above)**	
Total Nitrogen (TN) EMC Reduction by BMP Treatment Practice	**0**		**0**	
Total Nitrogen (TN) Mass Load Removal	**Same as for RR (above)**		**Same as for RR (above)**	
Channel Protection & Flood Mitigation	**Partial.** Designers can use the RRM spreadsheet to adjust the curve number for each design storm for the contributing drainage area, based on annual runoff volume reduction achieved.			

[1] CWP and CSN (2008), CWP (2007)

[2] CA = Compost Amended Soils, see Stormwater Design Specification No. 4.

[3] Compost amendments are generally not applicable for A and B soils, although it may be advisable to incorporate them on mass-graded B soils to maintain runoff reduction rates.

[4] Filter strips in HSG C and D should use composted amended soils to enhance runoff reduction capabilities. See Stormwater Design Specification No. 2: Sheetflow to Vegetated Filter Strip or Conserved Open Space.

SECTION 3: DESIGN TABLE

Not applicable.

SECTION 4: TYPICAL DETAILS

Not applicable.

SECTION 5: PHYSICAL FEASIBILITY & DESIGN APPLICATIONS

Compost amended soils are suitable for any pervious area where soils have been or will be compacted by the grading and construction process. They are particularly well suited when existing soils have low infiltration rates (HSG C and D) and when the pervious area will be used to filter runoff (downspout disconnections and grass channels). The area or strip of amended soils should be hydraulically connected to the stormwater conveyance system. Soil restoration is recommended for sites that will experience mass grading of more than a foot of cut and fill across the site.

Compost amendments are not recommended where:

- Existing soils have high infiltration rates (e.g., HSG A and B), although compost amendments may be needed at mass-graded B soils in order to maintain runoff reduction rates.
- The water table or bedrock is located within 1.5 feet of the soil surface.
- Slopes exceed 10%.
- Existing soils are saturated or seasonally wet.
- They would harm roots of existing trees (keep amendments outside the tree drip line).
- The downhill slope runs toward an existing or proposed building foundation.
- The contributing impervious surface area exceeds the surface area of the amended soils.

Compost amendments can be applied to the entire pervious area of a development or be applied only to select areas of the site to enhance the performance of runoff reduction practices. Some common design applications include:

- Reduce runoff from compacted lawns.
- Enhance rooftop disconnections on poor soils.
- Increase runoff reduction within a grass channel.
- Increase runoff reduction within a vegetated filter strip.
- Increase the runoff reduction function of a tree cluster or reforested area of the site.

SECTION 6: DESIGN CRITERIA

6.1. Performance When Used in Conjunction With Other Practices

As referenced in several of the other specifications, soil compost amendments can be used to enhance the runoff reduction capabilities of allied practices. The specifications for each of these practices contain design criteria for how compost amendments can be incorporated into those designs:

- Rooftop (impervious) Disconnection – see Stormwater Design Specification No. 1, Section 3.2.
- Vegetated Filter Strips – see Stormwater Design Specification No. 2, Section 6.1.
- Grass Channels – see Stormwater Design Specification No. 3, Section 6.5.
- Site Reforestation – see Appendix A of this design specification.

6.2. Soil Testing

Soil tests are required during two stages of the compost amendment process. The first testing is done to ascertain pre-construction soil properties at proposed amendment areas. The initial testing is used to determine soil properties to a depth 1 foot below the proposed amendment area, with respect to bulk density, pH, salts, and soil nutrients. These tests should be conducted every 5000 square feet, and are used to characterize potential drainage problems and determine what, if any, further soil amendments are needed.

The second soil test is taken at least one week after the compost has been incorporated into the soils. This soil analysis should be conducted by a reputable laboratory to determine whether any further nutritional requirements, pH adjustment, and organic matter adjustments are necessary for plant growth. This soil analysis should be done in conjunction with the final construction inspection to ensure tilling or subsoiling has achieved design depths.

6.3. Runoff Volume Reduction

The runoff volume reduction achieved by soil restoration depends on the site application and the pre-construction hydrologic soil group. When compost amendments are used simply to reduce runoff volume from compacted lawns, the lower runoff coefficients shown in **Table 4.2** can be used to lower the total treatment volume for the site as a whole. If the soil restoration area accepts runoff from adjacent impervious areas, the higher runoff reduction rates outlined in **Table 4.1** above may be used for the indicated practices.

Table 4.2. Runoff Coefficients for Use for Different Pervious Areas

Hydrologic Soil Group	Undisturbed Soils [1]	Disturbed Soils [2]	Restored and Reforested [3]
A	0.02	0.15	0.02
B	0.03	0.20	0.03
C	0.04	0.22	0.04
D	0.05	0.25	0.05

Notes:
[1] Portions of a new development site, outside the limits of disturbance, which are not graded and do not receive construction traffic.
[2] Previously developed sites, and any site area inside the limits of disturbance as shown on the E&S Control plan.
[3] Areas with restored soils that are also reforested to achieve a minimum 75% forest canopy

6.4. Determining Depth of Compost Incorporation

The depth of compost amendment is based on the relationship of the surface area of the soil amendment to the contributing area of impervious cover that it receives. **Table 4.3** presents some general guidance derived from soil modeling by Holman-Dodds (2004) that evaluates the required depth to which compost must be incorporated. Some adjustments to the recommended incorporation depth were made to reflect alternative recommendations of Roa Espinosa (2006), Balousek (2003), Chollak and Rosenfeld (1998) and others.

Table 4.3. Short-Cut Method to Determine Compost and Incorporation Depths

	Contributing Impervious Cover to Soil Amendment Area Ratio [1]			
	IC/SA = 0 [2]	**IC/SA = 0.5**	**IC/SA = 0.75**	**IC/SA = 1.0** [3]
Compost (in) [4]	2 to 4 [5]	3 to 6 [5]	4 to 8 [5]	6 to 10 [5]
Incorporation Depth (in)	6 to 10 [5]	8 to 12 [5]	15 to 18 [5]	18 to 24 [5]
Incorporation Method	Rototiller	Tiller	Subsoiler	Subsoiler

Notes:
[1] IC = contrib. impervious cover (sq. ft.) and SA = surface area of compost amendment (sq. ft.)
[2] For amendment of compacted lawns that do not receive off-site runoff
[3] In general, IC/SA ratios greater than 1 should be avoided
[4] Average depth of compost added
[5] Lower end for B soils, higher end for C/D soils

Once the area and depth of the compost amendments are known, the designer can estimate the total amount of compost needed, using an estimator developed by TCC, (1997):

$$C = A * D * 0.0031$$

Where: C = compost needed (cu. yds.)
A = area of soil amended (sq. ft.)
D = depth of compost added (in.)

6.5. Compost Specifications

The basic material specifications for compost amendments are outlined below:

- Compost shall be derived from plant material and provided by a member of the U.S. Composting Seal of Testing Assurance (STA) program. See www.compostingcouncil.org for a list of local providers.

- The compost shall be the result of the biological degradation and transformation of plant-derived materials under conditions that promote anaerobic decomposition. The material shall be well composted, free of viable weed seeds, and stable with regard to oxygen consumption and carbon dioxide generation. The compost shall have a moisture content that has no visible free water or dust produced when handling the material. It shall meet the following criteria, as reported by the U.S. Composting Council STA Compost Technical Data Sheet provided by the vendor:

  a. 100% of the material must pass through a half inch screen
  b. The pH of the material shall be between 6 and 8
  c. Manufactured inert material (plastic, concrete, ceramics, metal, etc.) shall be less than 1.0% by weight
  d. The organic matter content shall be between 35% and 65%
  e. Soluble salt content shall be less than 6.0 mmhos/cm
  f. Maturity should be greater than 80%
  g. Stability shall be 7 or less

h. Carbon/nitrogen ratio shall be less than 25:1
i. Trace metal test result = “pass”
j. The compost must have a dry bulk density ranging from 40 to 50 lbs./cu. ft^3.

SECTION 7: REGIONAL & SPECIAL CASE DESIGN ADAPTATIONS

7.1. Karst Terrain

No special adaptations are needed in karst terrain, but the designer should take soil tests to ensure that soil pH is adjusted to conform to pre-existing soil conditions found in limestone dominated areas.

7.2. Coastal Plain

Designers should evaluate drainage and water table elevations to ensure the entire depth of soil amendment will not become saturated (i.e., a minimum separation depth of 2 feet from groundwater). Compost amendments are most cost effective when used to boost the runoff reduction capability of grass vegetated filter strips, grass channels and rooftop disconnections.

7.3. Steep Terrain

Compost amendments are ineffective when longitudinal slopes exceed 5%, so some terracing may be needed on steeper slopes.

7.4. Cold Climate and Winter Performance

Soil restoration is not recommended for areas that will be used for snow storage.

7.5. Linear Highway Sites

Soil amendments can improve the runoff reduction of drainage swales in open section rights-of-way and highway medians.

SECTION 8: CONSTRUCTION

8.1. Construction Sequence

The construction sequence for compost amendments differs depending whether the practice will be applied to a large area or a narrow filter strip, such as in a rooftop disconnection or grass channel. For larger areas, a typical construction sequence is as follows:

Step 1. Prior to building, the proposed area should be deep tilled to a depth of 2 to 3 feet using a tractor and sub-soiler with two deep shanks (curved metal bars) to create rips perpendicular to the direction of flow. (This step is usually omitted when compost is used for narrower filter strips.)

Step 2. A second deep tilling to a depth of 12 to 18 inches is needed after final building lots have been graded.

Step 3. It is important to have dry conditions at the site prior to incorporating compost.

Step 4. An acceptable compost mix is then incorporated into the soil using a roto-tiller or similar equipment at the volumetric rate of 1 part compost to 2 parts soil.

Step 5. The site should be leveled and seeds or sod used to establish a vigorous grass cover. Lime or irrigation may initially be needed to help the grass grow quickly.

Step 6. Areas of compost amendments exceeding 2500 square feet should employ simple erosion control measures, such as silt fence, to reduce the potential for erosion and trap sediment.

8.2. Construction Inspection

Construction inspection involves digging a test pit to verify the depth of mulch, amended soil and scarification. A rod penetrometer should be used to establish the depth of uncompacted soil at one location per 10,000 square feet.

SECTION 9: MAINTENANCE

9.1. Maintenance Agreements

When soil compost amendments are applied on private residential lots, homeowners will need to be educated on their routine maintenance needs, understand the long-term maintenance plan, and be subject to a deed restriction or other mechanism enforceable by the qualifying local program to ensure that infiltrating areas are not converted or disturbed. The mechanism should, ideally, grant authority for local agencies to access the property for inspection or corrective action. In addition, the GPS coordinates for all amended areas should be provided upon facility acceptance to ensure long term tracking.

A simple maintenance agreement should be provided if soil restoration is associated with more than 10,000 square feet of reforestation. A conservation easement or deed restriction, which also identifies a responsible party, may be required to make sure the newly developing forest cannot be cleared or developed management is accomplished (i.e., thinning, invasive plant removal, etc.). Soil compost amendments within a filter strip or grass channel should be located in a public right-of-way, or within a dedicated stormwater or drainage easement.

9.2. First Year Maintenance Operations

In order to ensure the success of soil compost amendments, the following tasks must be undertaken in the first year following soil restoration:

Initial inspections. For the first six months following the incorporation of soil amendments, the site should be inspected at least once after each storm event that exceeds 1/2-inch of rainfall.

Spot Reseeding. Inspectors should look for bare or eroding areas in the contributing drainage area or around the soil restoration area and make sure they are immediately stabilized with grass cover.

Fertilization. Depending on the amended soils test, a one-time, spot fertilization may be needed in the fall after the first growing season to increase plant vigor.

Watering. Water once every three days for the first month, and then weekly during the first year (April-October), depending on rainfall.

9.3. Ongoing Maintenance

There are no major on-going maintenance needs associated with soil compost amendments, although the owners may want to de-thatch the turf every few years to increase permeability. The owner should also be aware that there are maintenance tasks needed for filter strips, grass channels, and reforestation areas. An example maintenance inspection checklist for an area of Soil Compost Amendments can be accessed in Appendix C of Chapter 9 of the *Virginia Stormwater Management Handbook* (2010).

SECTION 10. COMMUNITY & ENVIRONMENTAL CONCERNS

Not applicable.

SECTION 11: REFERENCES

Balusek. 2003. *Quantifying decreases in stormwater runoff from deep-tilling, chisel-planting and compost amendments*. Dane County Land Conservation Department. Madison, Wisconsin.

Chollak, T. and P. Rosenfeld. 1998. *Guidelines for Landscaping with Compost-Amended Soils.* City of Redmond Public Works. Redmond, WA. Available online at: http://www.ci.redmond.wa.us/insidecityhall/publicworks/environment/pdfs/compostamendedsoils.pdf

City of Portland. 2008. "Soil Specification for Vegetated Stormwater Facilities." *Portland Stormwater Management Manual*. Portland, Oregon.

Composting Council (TCC). 1997. *Development of a Landscape Architect Specification for Compost Utilization*. Alexandria, VA. http://www.cwc.org/organics/org972rpt.pdf

Holman-Dodds, L. 2004. *Chapter 6. Assessing Infiltration-Based Stormwater Practices*. PhD Dissertation. Department of Hydroscience and Engineering. University of Iowa. Iowa City, IA.

Lenhart, J. 2007. "Compost as a Soil Amendment for Water Quality Treatment Facilities." *Proceedings: 2007 LID Conference*. Wilmington, NC.

Low Impact Development Center. *Guideline for Soil Amendments*. Available online at:

http://www.lowimpactdevelopment.org/epa03/soilamend.htm

Roa-Espinosa. 2006. *An Introduction to Soil Compaction and the Subsoiling Practice. Technical Note.* Dane County Land Conservation Department. Madison,Wisconsin.

Soils for Salmon. 2003. *Soil Restoration and Compost Amendments*. Available online at: http://www.soilsforsalmon.org/pdf/SoilsforSalmonLIDrev9-16-04.pdf

APPENDIX 4-A

INITIAL MINIMUM DESIGN CRITERIA FOR REFORESTATION, DISCONNECTION, FILTER STRIPS AND GRASS CHANNELS

SECTION 4-A.1: SITE REFORESTATION

Several design criteria apply when compost amendments are used to enhance the performance of reforested areas. Site reforestation involves planting trees on existing turf or barren ground at a development site with the explicit goal of establishing a mature forest canopy that will intercept rainfall, increase evapotranspiration rates, and enhance soil infiltration rates. Reforestation areas at larger development sites (and individual trees at smaller development sites) are eligible under the following qualifying conditions.

- The minimum contiguous area of reforestation must be greater than 5,000 square feet.
- A long term vegetation management plan must be prepared and filed with the local review authority in order to maintain the reforestation area in a natural forest condition.
- The reforestation area must be protected by a perpetual stormwater easement or deed restriction which stipulates that no future development or disturbance may occur within the area.
- Reforestation methods must achieve 75% forest canopy within ten years.
- The planting plan must be approved by the appropriate local forestry or conservation authority, including any special site preparation needs.
- The construction contract should contain a care and replacement warranty extending at least 3 growing seasons, to ensure adequate growth and survival of the plant community.
- The reforestation area shall be shown on all construction drawings and E&S Control plans during construction.

SECTION 4-A.2: SIMPLE DOWNSPOUT DISCONNECTION

See VA DEQ Stormwater Design Specification No. 1.

SECTION 4-A.3: FILTER STRIP

See VA DEQ Stormwater Design Specification No. 2.

SECTION 4-A.4: GRASS CHANNEL

See VA DEQ Stormwater Design Specification No. 3.

VIRGINIA DEQ STORMWATER
DESIGN SPECIFICATION No. 5

VEGETATED ROOF

Version 2.3
March 1, 2011

SECTION 1: DESCRIPTION

Vegetated roofs (also known as *green roofs*, *living roofs* or *ecoroofs*) are alternative roof surfaces that typically consist of waterproofing and drainage materials and an engineered growing media that is designed to support plant growth. Vegetated roofs capture and temporarily store stormwater runoff in the growing media before it is conveyed into the storm drain system. A portion of the captured stormwater evaporates or is taken up by plants, which helps reduce runoff volumes, peak runoff rates, and pollutant loads on development sites.

There are two different types of vegetated roof systems: *intensive* vegetated roofs and *extensive* vegetated roofs. Intensive systems have a deeper growing media layer that ranges from 6 inches to 4 feet thick, which is planted with a wider variety of plants, including trees. By contrast, extensive systems typically have much shallower growing media (2 to 6 inches), which is planted with carefully selected drought tolerant vegetation. Extensive vegetated roofs are much lighter and less expensive than intensive vegetated roofs and are recommended for use on most development and redevelopment sites.

NOTE: This specification is intended for situations where the primary design objective of the vegetated roof is stormwater management and, unless specified otherwise, addresses extensive roof systems.

Designers may wish to pursue other design objectives for vegetated roofs, such as energy efficiency, green building or LEED points, architectural considerations, visual amenities and landscaping features, which are often maximized with intensive vegetated roof systems. However, these design objectives are beyond the scope of this specification.

Vegetated roofs typically contain a layered system of roofing, which is designed to support plant growth and retain water for plant uptake while preventing ponding on the roof surface. The roofs are designed so that water drains vertically through the media and then horizontally along a waterproofing layer towards the outlet. Extensive vegetated roofs are designed to have minimal maintenance requirements. Plant species are selected so that the roof does not need supplemental irrigation or fertilization after vegetation is initially established.

SECTION 2: PERFORMANCE

The overall stormwater functions of vegetated roofs are summarized in **Table 5.1**.

Table 5.1: Summary of Stormwater Functions Provided by Vegetated Roofs [1]

Stormwater Function	Level 1 Design	Level 2 Design
Annual Runoff Volume Reduction (RR)	45%	60%
Total Phosphorus (TP) EMC Reduction[2] by BMP Treatment Process	0	0
Total Phosphorus (TP) Mass Load Removal	45%	60%
Total Nitrogen (TN) EMC Reduction[2] by BMP Treatment Process	0	0
Total Nitrogen (TN) Mass Load Removal	45%	60%
Channel Protection & Flood Mitigation [3]	Use the following Curve Numbers (CN) for Design Storm events: 1-year storm = 64; 2-year storm = 66; 10-year storm = 72; and the 100 year storm = 75	

[1] Sources: CWP and CSN (2008) and CWP (2007).
[2] Moran et al (2004) and Clark et al (2008) indicate no nutrient reduction or even negative nutrient reduction (due to leaching from the media) in early stages of vegetated roof development.
[3] See Miller (2008), NVRC (2007) and MDE (2008)

SECTION 3: DESIGN TABLE

The major design goal for Vegetated Roofs is to maximize nutrient removal and runoff volume reduction. To this end, designers may choose the baseline design (Level 1) or choose an enhanced (Level 2) design that maximizes nutrient and runoff reduction. In general, most intensive vegetated roof designs will automatically qualify as being Level 2. **Table 5.2** (next page) lists the design criteria for Level 1 and 2 designs.

Table 5.2. Green Roof Design Guidance

Level 1 Design (RR:45; TP:0; TN:0)	Level 2 Design (RR: 60; TP:0; TN:0)
Tv = 1.0 (Rv)[1] (A)/12	Tv = 1.1 (Rv)[1] (A)/12
Depth of media up to 4 inches	Media depth 4 to 8 inches
Drainage mats	2-inch stone drainage layer
No more than 20% organic matter in media	No more than 10% organic matter in media
All Designs: Must be in conformance to ASTM (2005) International Green (Vegetated) Roof Stds.	
[1]Rv represents the runoff coefficient for a conventional roof, which will usually be 0.95. The runoff reduction rate applied to the vegetated roof is for “capturing” the Treatment Volume (Tv) compared to what a conventional roof would produce as runoff.	

SECTION 4: TYPICAL DETAILS

Figure 5.1. Photos of Vegetated Roof Cross-Sections (source: B. Hunt, NCSU)

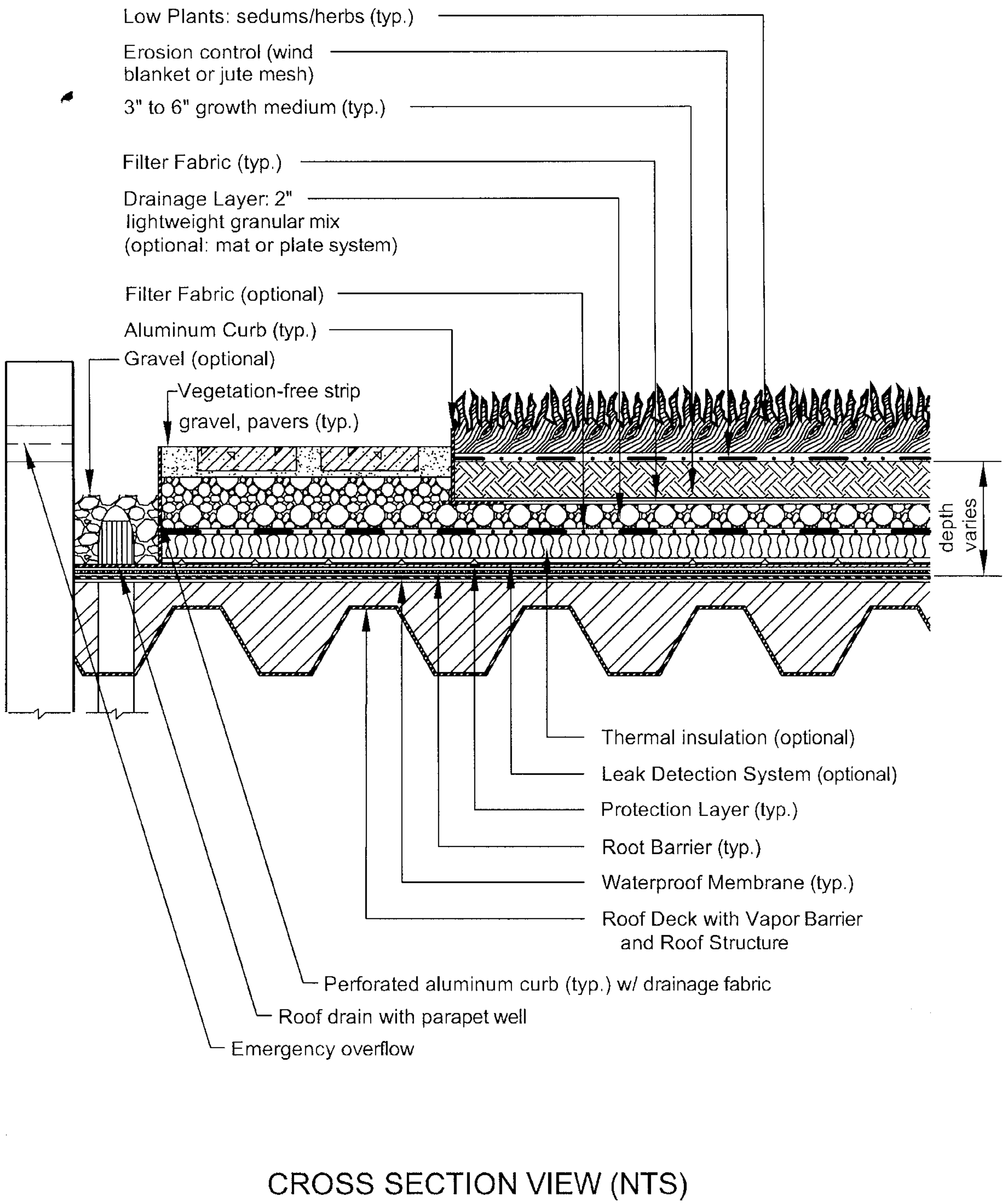


Figure 5.2. Typical Section – Extensive Vegetated Roof
(Source: Northern VA Regional Commission)

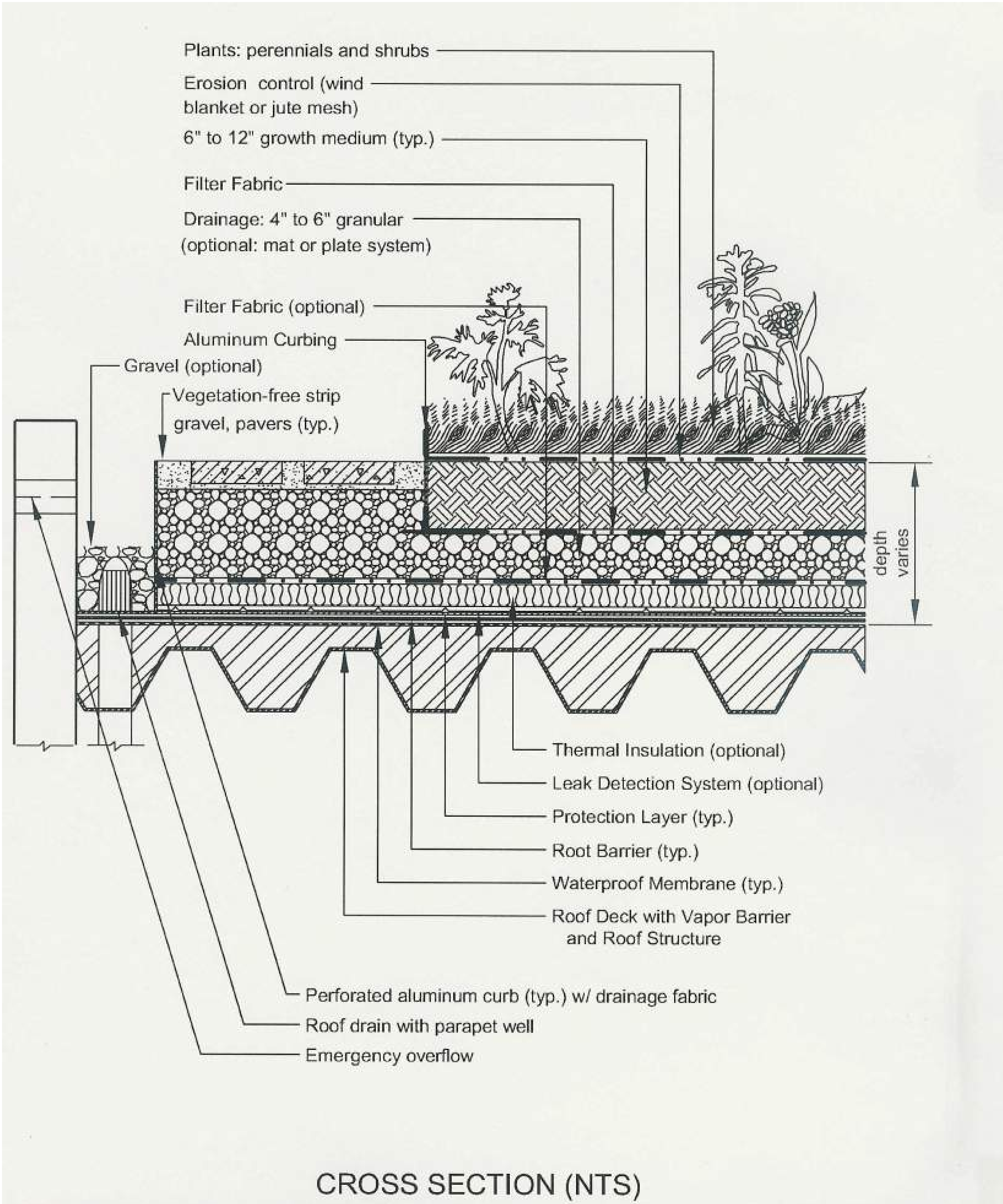


Figure 5.3. Typical Section – Intensive Vegetated Roof (Source: Northern VA Regional Commission)

SECTION 5: PHYSICAL FEASIBILITY & DESIGN APPLICATIONS

5.1. Typical applications

Vegetated roofs are ideal for use on commercial, institutional, municipal and multi-family residential buildings. They are particularly well suited for use on ultra-urban development and redevelopment sites. Vegetated roofs can be used on a variety of rooftops, including the following:

- Non-residential buildings (e.g. commercial, industrial, institutional and transportation uses)
- Multi-family residential buildings (e.g condominiums or apartments)
- Mixed-use buildings

Local regulations may also permit the use of vegetated roofs on single family residential roofs.

5.2. Common Site Constraints

Structural Capacity of the Roof. When designing a vegetated roof, designers must not only consider the stormwater storage capacity of the vegetated roof, but also its structural capacity to support the weight of the additional water. A conventional rooftop typically must be designed to support an additional 15 to 30 pounds per square foot (psf) for an extensive vegetated roof. As a result, a structural engineer, architect or other qualified professional should be involved with all vegetated roof designs to ensure that the building has enough structural capacity to support a vegetated roof.

Roof Pitch. Treatment volume (Tv) is maximized on relatively flat roofs (a pitch of 1 to 2%). Some pitch is needed to promote positive drainage and prevent ponding and/or saturation of the growing media. Vegetated roofs can be installed on rooftops with slopes up to 25% if baffles, grids, or strips are used to prevent slippage of the media. The effective treatment volume (Tv), however, diminishes on rooftops with steep pitches (Van Woert et al, 2005).

Roof Access. Adequate access to the roof must be available to deliver construction materials and perform routine maintenance. Roof access can be achieved either by an interior stairway through a penthouse or by an alternating tread device with a roof hatch or trap door not less than 16 square feet in area and with a minimum dimension of 24 inches (NVRC, 2007). Designers should also consider how they will get construction materials up to the roof (e.g., by elevator or crane), and how construction materials will be stockpiled in the confined space.

Roof Type. Vegetated roofs can be applied to most roof surfaces, although concrete roof decks are preferred. Certain roof materials, such as exposed treated wood and uncoated galvanized metal, may not be appropriate for vegetated rooftops due to pollutant leaching through the media (Clark et al, 2008).

Setbacks. Vegetated roofs should not be located near rooftop electrical and HVAC systems. A 2-foot wide vegetation-free zone is recommended along the perimeter of the roof, with a 1-foot vegetation-free zone around all roof penetrations, to act as a firebreak. The 2-foot setback may be relaxed to 1 foot for very small vegetated roof applications.

Retrofitting Green Roofs: Key feasibility factors to consider when evaluating a retrofit include the area, age and accessibility of the existing roof, and the capability of the building's owners to maintain it. Options for green roof retrofits are described in Profile Sheet RR-3 of Schueler et al (2007). The structural capacity of the existing rooftop can be a major constraint to a green roof retrofits.

Local Building Codes. Building codes often differ in each municipality, and local planning and zoning authorities should be consulted to obtain proper permits. In addition, the vegetated roof design should comply with the Virginia Uniform Statewide Building Code (VUSBC) with respect to roof drains and emergency overflow devices.

Construction Cost. When viewed strictly as stormwater treatment systems, vegetated roofs can cost between $12 and $25 per square foot, ranking them among the most costly stormwater practices available (Moran et al, 2005, Schueler et al 2007). These cost analyses, however, do not include life cycle cost savings relating to increased energy efficiency, higher rents due to green building scores, and increased roof longevity. These benefits over the life cycle of a vegetated roof may make it a more attractive investment. In addition, several communities may offer subsidies or financial incentives for installing vegetated roofs.

Risks of Leaky Roofs. Although well designed and installed green roofs have less problems with roof leaks than traditional roofs, there is a perception among property managers, insurers and product fabricators that this emerging technology could have a greater risk of problems. For an excellent discussion on how to properly manage risk in vegetated roof installations, see Chapter 9 in Weiler and Scholz-Barth (2009).

SECTION 6: DESIGN CRITERIA

6.1. Overall Sizing

Vegetated roof areas should be sized to capture a portion of the Treatment Volume (Tv). The required size of a vegetated roof will depend on several factors, including the porosity and hydraulic conductivity of the growing media and the underlying drainage materials. Site designers and planners should consult with vegetated roof manufacturers and material suppliers for specific sizing guidelines. As a general sizing rule, the following equation can be used to determine the water quality treatment storage volume retained by a vegetated roof:

$$Tv = (RA * D * P)/12$$

Where,
- Tv = storage volume (cu. ft.)
- RA = vegetated roof area (sq. ft.)
- D = media depth (in.)
- P = media porosity (usually 0.3, but consult manufacturer specifications)

The resulting Tv can then be compared to the required Tv for the entire rooftop area (including all non-vegetated areas) to determine if it meets or exceeds the required Tv for Level 1 or Level 2 design, as shown in **Table 5.2** above.

Guidance for selecting the appropriate post development CN for the vegetated roof for four different design storms is also provided in **Table 5.2**; in general, lower curve numbers are associated with more frequent design storms. In most cases, the maximum design storm is the 10-year event.

6.2. Structural Capacity of the Roof

Vegetated roofs can be limited by the additional weight of the fully saturated soil and plants, in terms of the physical capacity of the roof to bear structural loads. The designer should consult with a licensed structural engineer or architect to ensure that the building will be able to support the additional live and dead structural load and determine the maximum depth of the vegetated roof system and any needed structural reinforcement.

In most cases, fully-saturated extensive vegetated roofs have loads of about 15 to 25 lbs./sq. ft., which is fairly similar to traditional new rooftops (12 to 15 lbs./sq. ft.) that have a waterproofing layer anchored with stone ballast. For an excellent discussion of vegetated roof structural design issues, consult Chapter 9 in Weiler and Scholz-Barth (2009) and ASTM E-2397, *Standard Practice for Determination of Dead Loads and Live Loads Associated with Green (Vegetated) Roof Systems*.

6.3. Functional Elements of a Vegetated Roof System

A vegetated roof is composed of up to eight different systems or layers, from bottom to top, that are combined together to protect the roof and maintain a vigorous cover. Designers can employ a wide range of materials for each layer, which can differ in cost, performance, and structural load. The entire system as a whole must be assessed to meet design requirements. Some manufacturers offer proprietary vegetated roofing systems, whereas in other cases, the designer or architect must assemble their own system, in which case they are advised to consult Weiler and Scholz-Barth (2009), Snodgrass and Snodgrass (2006) and Dunnett and Kingsbury (2004)**.**

1. ***Deck Layer.*** The roof deck layer is the foundation of a vegetated roof. It and may be composed of concrete, wood, metal, plastic, gypsum or a composite material. The type of deck material determines the strength, load bearing capacity, longevity and potential need for insulation in the vegetated roof system. In general, concrete decks are preferred for vegetated roofs, although other materials can be used as long as the appropriate system components are matched to them.

2. ***Waterproofing Layer.*** All vegetated roof systems must include an effective and reliable waterproofing layer to prevent water damage through the deck layer. A wide range of waterproofing materials can be used, including built up roofs, modified bitumen, single-ply, and liquid-applied methods (see Weiler and Scholz-Barth, 2009 and Snodgrass and

Snodgrass, 2006). The waterproofing layer must be 100% waterproof and have an expected life span as long as any other element of the vegetated roof system.

3. ***Insulation Layer.*** Many vegetated rooftops contain an insulation layer, usually located above, but sometimes below, the waterproofing layer. The insulation increases the energy efficiency of the building and/or protects the roof deck (particularly for metal roofs). According to Snodgrass and Snodgrass (2006), the trend is to install insulation on the outside of the building, in part to avoid mildew problems.

4. ***Root Barrier.*** The next layer of a vegetated roof system is a root barrier that protects the waterproofing membrane from root penetration. A wide range of root barrier options are described in Weiler and Scholz-Barth (2009). Chemical root barriers or physical root barriers that have been impregnated with pesticides, metals or other chemicals that could leach into stormwater runoff should be avoided.

5. ***Drainage Layer and Drainage System.*** A drainage layer is then placed between the root barrier and the growing media to quickly remove excess water from the vegetation root zone. The drainage layer should consist of synthetic or inorganic materials (e.g. gravel, recycled polyethylene, etc.) that are capable of retaining water and providing efficient drainage. A wide range of prefabricated water cups or plastic modules can be used, as well as a traditional system of protected roof drains, conductors and roof leader. The required depth of the drainage layer is governed by both the required stormwater storage capacity and the structural capacity of the rooftop. ASTM E2396 and E2398 can be used to evaluate alternative material specifications.

6. ***Root-Permeable Filter Fabric.*** A semi-permeable polypropylene filter fabric is normally placed between the drainage layer and the growing media to prevent the media from migrating into the drainage layer and clogging it.

7. ***Growing Media.*** The next layer in an extensive vegetated roof is the growing media, which is typically 4 to 8 inches deep. The depth and composition of the media is described in Section 6.5.

8. ***Plant Cover.*** The top layer of a vegetated roof consists of non-native, slow-growing, shallow-rooted, perennial, succulent plants that can withstand harsh conditions at the roof surface. Guidance on selecting the appropriate vegetated roof plants for hardiness zones in the Chesapeake Bay watershed can be found in Snodgrass and Snodgrass (2006). A mix of base ground covers (usually *Sedum* species) and accent plants can be used to enhance the visual amenity value of a green roof.

6.4. Pretreatment

Pretreatment is not needed for green roofs.

6.5. Filter Media Composition

The recommended growing media for extensive vegetated roofs is composed of approximately 80% to 90% lightweight inorganic materials, such as expanded slates, shales or clays, pumice, scoria or other similar materials. The remaining media should contain no more than 20% organic matter, normally well-aged compost (see Stormwater Design Specification No. 4). The percentage of organic matter should be limited, since it can leach nutrients into the runoff from the roof and clog the permeable filter fabric. The growing media should have a maximum water retention capacity of around 30%. It is advisable to mix the media in a batch facility prior to delivery to the roof. More information on growing media can be found in Weiler and Scholz-Barth (2009) and Snodgrass and Snodgrass (2006).

The composition of growing media for intensive vegetated roofs may be different, and it is often much greater in depth (e.g., 6 to 48 inches). If trees are included in the vegetated roof planting plan, the growing media must be at least 4 feet deep to provide enough soil volume for the root structure of mature trees.

6.6. Conveyance and Overflow

The drainage layer below the growth media should be designed to convey the 10-year storm without backing water up to into the growing media. The drainage layer should convey flow to an outlet or overflow system such as a traditional rooftop drainage system with inlets set slightly above the elevation of the vegetated roof surface. Roof drains immediately adjacent to the growing media should be boxed and protected by flashing extending at least 3 inches above the growing media to prevent clogging.

6.7. Vegetation and Surface Cover

A planting plan must be prepared for a vegetated roof by a landscape architect, botanist or other professional experienced with vegetated roofs, and it must be reviewed and approved by the local development review authority.

Plant selection for vegetated rooftops is an integral design consideration, which is governed by local climate and design objectives. The primary ground cover for most vegetated roof installations is a hardy, low-growing succulent, such as *Sedum*, *Delosperma*, *Talinum*, *Semperivum* or *Hieracium* that is matched to the local climate conditions and can tolerate the difficult growing conditions found on building rooftops (Snodgrass and Snodgrass, 2006). Much of the Chesapeake Bay watershed lies within USDA Plant Hardiness Zone 7, although some northern areas of the watershed fall in the colder Hardiness Zone 6, and some areas in the extreme southeastern portion of the watershed fall in the slightly warmer Hardiness Zone 8 (AHS, 2003).

A list of some common vegetated roof plant species that work well in the Chesapeake Bay watershed can be found in **Table 5.3** below. Designers may also want to directly contact the short list of mid-Atlantic nurseries for vegetated roof plant recommendations and availability (see **Table 5.3**).

- Plant choices can be much more diverse for deeper intensive vegetated roof systems. Herbs, forbs, grasses, shrubs and even trees can be used, but designers should understand they have higher watering, weeding and landscape maintenance requirements.
- The species and layout of the planting plan should reflect the location of building, in terms of its height, exposure to wind, snow loading, heat stress, orientation to the sun, and shading by surrounding buildings. In addition, plants should be selected that are fire resistant and able to withstand heat, cold and high winds.

Table 5.3. Ground Covers for Vegetated Roofs in Chesapeake Bay Watershed

Plant Hardiness Zone 7	Plant Hardiness Zone 6
Delosperma 'Tiffendell Magenta'	*Delosperma cooperi*
Hieracium lanatum	*Delosperma ecklonis var.latifolia*
Sedum lineare 'Variegatum'	*Hieracium villosum*
Sedum makinoi	*Orostachys boehmeri*
Sedum tetractinum	*Sedum hispanicum*
Sedum stoloniferum	*Sedum pluricaule var. ezawe*
	Sedum urvillei
Note: Landscape architects should choose species based on shade tolerance, ability to sow or not, foliage height, and spreading rate. See Snodgrass and Snodgrass (2006) for definitive list of green roof plants, including accent plants.	
Green Roof Plant Vendors in Mid-Atlantic States	
Riverbend Nursery 1295 Mt. Elbert Road NW Riner, VA 24149 800-638-3362 www.riverbendnursery.com	Emery Knolls Farm 3410 Ady Road Street. Maryland 21154 410-452-5880 www.greenroofplants.com
Carolina Stonecrops, Inc. 159 Bay Shore Drive Nebo, NC 28761 828-659-2851 www.greenroofplants4u.com	North Creek Nurseries, Inc. 388 North Creek Road Landenburg, PA 19350 877-326-7584 www.northcreeknurseries.com
Roofscapes, Inc. 7114 McCallum Street Philadelphia, PA 19119 215-247-8784 www.roofmeadow.com	

- Designers should also match species to the expected rooting depth of the growing media, which can also provide enough lateral growth to stabilize the growing media surface. The planting plan should usually include several accent plants to provide diversity and seasonal color. For a comprehensive resource on vegetated roof plant selection, consult Snodgrass and Snodgrass (2006).
- It is also important to note that most vegetated roof plant species will *not* be native to the Chesapeake Bay watershed (which is contrast to *native* plant recommendations for other stormwater practices, such as bioretention and constructed wetlands).

- Given the limited number of vegetated roof plant nurseries in the region, designers should order plants 6 to 12 months prior to the expected planting date. It is also advisable to have plant materials contract-grown (see **Table 5.3** above for a current list of mid-Atlantic vegetated roof plant nurseries).
- When appropriate species are selected, most vegetated roofs in the Bay watershed will not require supplemental irrigation, except for temporary irrigation during dry months as the vegetated roof is established. The planting window extends from the spring to early fall, although it is important to allow plants to root thoroughly before the first killing frost.
- Plants can be established using cuttings, plugs, mats, and, more rarely, seeding or containers. Several vendors also sell mats, rolls, or proprietary vegetated roof planting modules. For the pros and cons of each method, see Snodgrass and Snodgrass (2006).
- The goal for vegetated roof systems designed for stormwater management is to establish a full and vigorous cover of low-maintenance vegetation that is self-sustaining and requires minimal mowing, trimming and weeding.
- The vegetated roof design should include non-vegetated walkways (e.g., permeable paver blocks) to allow for easy access to the roof for weeding and making spot repairs.

6.8. Material Specifications

Standards specifications for North American vegetated roofs continue to evolve, and no universal material specifications exist that cover the wide range of roof types and system components currently available. The American Society for Testing and Materials (ASTM) has recently issued several overarching vegetated roof standards, which are described and referenced in **Table 5.4** below.

Designers and reviewers should also fully understand manufacturer specifications for each system component listed in **Section 6.3**, particularly if they choose to install proprietary "complete" vegetated roof systems or modules.

Table 5.4. Extensive Vegetated Roof Material Specifications

Material	Specification
Roof	Structural Capacity should conform to ASTM E-2397-05, *Practice for Determination of Live Loads and Dead Loads Associated with Green (Vegetated) Roof Systems*. In addition, use standard test methods ASTM E2398-05 for *Water Capture and Media Retention of Geocomposite Drain Layers for Green (Vegetated) Roof Systems*, and ASTME 2399-05 for *Maximum Media Density for Dead Load Analysis*.
Waterproof Membrane	See Chapter 6 of Weiler and Scholz-Barth (2009) for waterproofing options that are designed to convey water horizontally across the roof surface to drains or gutter. This layer may sometimes act as a root barrier.
Root Barrier	Impermeable liner that impedes root penetration of the membrane.
Drainage Layer	1 to 2 inch layer of clean, washed granular material, such as ASTM D 448 size No. 8 stone. Roof drains and emergency overflow should be designed in accordance with VUSBC.
Filter Fabric	Needled, non-woven, polypropylene geotextile. Density (ASTM D3776) > 16 oz./sq. yd., or approved equivalent. Puncture resistance (ASTM D4833) > 220 lbs., or approved equivalent.
Growth Media	80% lightweight inorganic materials and 20% organic matter (e.g. well-aged compost). Media should have a maximum water retention capacity of around 30%. Media should provide sufficient nutrients and water holding capacity to support the proposed plant materials. Determine acceptable saturated water permeability using ASTM E2396-05.
Plant Materials	Sedum, herbaceous plants, and perennial grasses that are shallow-rooted, self-sustaining, and tolerant of direct sunlight, drought, wind, and frost. See ASTM E2400-06, *Guide for Selection, Installation and Maintenance of Plants for Green (Vegetated) Roof Systems*.

SECTION 7: REGIONAL & SPECIAL CASE DESIGN ADAPTATIONS

7.1. Karst Terrain

Vegetated roofs are an ideal stormwater control measure for karst terrain, although it is advisable to direct downspout discharges at least 15 feet away from the building foundation to minimize the risk of sinkhole formation.

7.2. Coastal Plain

Vegetated roofs are an acceptable runoff reduction practice for the coastal plain, but they have a limited water quality function, since rooftops are not a major loading source for nutrients or bacteria. Designers should also choose plant materials that can tolerate drought and salt spray.

7.3. Cold Climate and Winter Performance

Several design adaptations may be needed for vegetated roofs. The most important is to match the plant species to the appropriate plant hardiness zone. In parts of the Bay watershed with colder climates, vegetated roofs should be designed so the growing media is not subject to freeze-thaw, and provide greater structural capacity to account for winter snow loads.

7.3. Acid Rain

Much of the Bay watershed experiences acid rain, with rainfall pH ranging from 3.9 to 5.1. Research has shown that vegetated roof growing media can neutralize acid rain (Berhage et al, 2007), but it is not clear whether acid rain will impair plant growth or leach minerals from the growing media.

SECTION 8: CONSTRUCTION

8.1. Construction Sequence

Given the diversity of extensive vegetated roof designs, there is no typical step-by-step construction sequence for proper installation. The following general construction considerations are noted:

- Construct the roof deck with the appropriate slope and material.
- Install the waterproofing method, according to manufacturer's specifications.
- Conduct a flood test to ensure the system is water tight by placing at least 2 inches of water over the membrane for 48 hours to confirm the integrity of the waterproofing system.
- Add additional system components (e.g., insulation, root barrier, drainage layer and interior drainage system, and filter fabric), taking care not to damage the waterproofing. Drain collars and protective flashing should be installed to ensure free flow of excess stormwater.
- The growing media should be mixed prior to delivery to the site. Media should be spread evenly over the filter fabric surface. The growing media should be covered until planting to prevent weeds from growing. Sheets of exterior grade plywood can also be laid over the growing media to accommodate foot or wheelbarrow traffic. Foot traffic and equipment traffic should be limited over the growing media to reduce compaction.
- The growing media should be moistened prior to planting, and then planted with the ground cover and other plant materials, per the planting plan, or in accordance with ASTM E2400. Plants should be watered immediately after installation and routinely during establishment.
- It generally takes 12 to 18 months to fully establish the vegetated roof. An initial fertilization using slow release fertilizer (e.g., 14-14-14) with adequate minerals is often needed to support growth. Temporary watering may also be needed during the first summer, if drought conditions persist. Hand weeding is also critical in the first two years (see Table 10.1 of Weiler and Scholz-Barth, 2009, for a photo guide of common rooftop weeds).
- Most construction contracts should contain a Care and Replacement Warranty that specifies a 75% minimum survival after the first growing season of species planted and a minimum effective vegetative ground cover of 75% for flat roofs and 90% for pitched roofs.

8.2. Construction Inspection

Inspections during construction are needed to ensure that the vegetated roof is built in accordance with these specifications. Detailed inspection checklists should be used that include sign-offs by qualified individuals at critical stages of construction and confirm that the contractor's interpretation of the plan is consistent with the intent of the designer and/or manufacturer.

An experienced installer should be retained to construct the vegetated roof system. The vegetated roof should be constructed in sections for easier inspection and maintenance access to the membrane and roof drains. Careful construction supervision is needed during several steps of vegetated roof installation, as follows:

- During placement of the waterproofing layer, to ensure that it is properly installed and watertight;
- During placement of the drainage layer and drainage system;
- During placement of the growing media, to confirm that it meets the specifications and is applied to the correct depth;
- Upon installation of plants, to ensure they conform to the planting plan;
- Before issuing use and occupancy approvals; and
- At the end of the first or second growing season, to ensure desired surface cover specified in the Care and Replacement Warranty has been achieved.

SECTION 9: MAINTENANCE

9.1. Maintenance Inspections and Ongoing Operations

A vegetated roof should be inspected twice a year during the growing season to assess vegetative cover, and to look for leaks, drainage problems and any rooftop structural concerns (see **Table 5.5** below). In addition, the vegetated roof should be hand-weeded to remove invasive or volunteer plants, and plants/media should be added to repair bare areas (refer to ASTM E2400). Many practitioners also recommend an annual application of slow release fertilizer in the first five years after the vegetated roof is installed.

If a roof leak is suspected, it is advisable to perform an electric leak survey (i.e., Electrical Field Vector Mapping) to pinpoint the exact location, make localized repairs, and then reestablish system components and ground cover.

The use of herbicides, insecticides, and fungicides should be avoided, since their presence could hasten degradation of the waterproof membrane. Also, power-washing and other exterior maintenance operations should be avoided so that cleaning agents and other chemicals do not harm the vegetated roof plant communities.

Written documentation between the local inspection authority and the property owner or manager should be required, in order to ensure adequate notification or authorization for access to conduct inspections. An example maintenance inspection checklist for Vegetated Roofs can be accessed in Appendix C of Chapter 9 of the *Virginia Stormwater Management Handbook* (2010).

Table 5.5. Typical Maintenance Activities Associated with Green Roofs

Activity	Schedule
• Water to promote plant growth and survival. • Inspect the vegetated roof and replace any dead or dying vegetation.	As Needed (Following Construction)
• Inspect the waterproof membrane for leaking or cracks. • Annual fertilization (first five years). • Weeding to remove invasive plants. • Inspect roof drains, scuppers and gutters to ensure they are not overgrown or have organic matter deposits. Remove any accumulated organic matter or debris. • Inspect the green roof for dead, dying, or invasive vegetation. Plant replacement vegetation as needed.	Semi-Annually

SECTION 10: COMMUNITY & ENVIRONMENTAL CONCERNS

Not applicable.

SECTION 11: REFERENCES

American Horticultural Society (AHS). 2003. *United States Department of Agriculture Plant Hardiness Zone Map*. Alexandria, VA.

ASTM International. 2005. *Standard Test Method for Maximum Media Density for Dead Load Analysis of Green (Vegetated) Roof Systems*. Standard E2399-05. ASTM, International. West Conshohocken, PA. available online: http://www.astm.org/ Standards/E2399.htm.

ASTM International. 2005. *Standard Test Method for Saturated Water Permeability of Granular Drainage Media [Falling-Head Method] for Green (Vegetated) Roof Systems*. Standard E2396-05. ASTM, International. West Conshohocken, PA. available online: http://www.astm.org/ Standards/E2396.htm.

ASTM International. 2005. *Standard Test Method for Water Capture and Media Retention of Geocomposite Drain Layers for Green (Vegetated) Roof Systems*. Standard E2398-05. ASTM, International. West Conshohocken, PA. available online: http://www.astm.org/ Standards/E2398.htm.

ASTM International. 2005. *Standard Practice for Determination of Dead Loads and Live Loads Associated with Green (Vegetated) Roof Systems*. Standard E2397-05. ASTM, International. West Conshohocken, PA. available online: http://www.astm.org/ Standards/E2397.htm.

ASTM International. 2006. *Standard Guide for Selection, Installation and Maintenance of Plants for Green (Vegetated) Roof Systems*. Standard E2400-06. ASTM, International. West Conshohocken, PA. available online: http://www.astm.org/Standards/ E2400.htm.

Berhage, R., A. Jarrett, D. Beattie and others. 2007. *Quantifying evaporation and transpiration water losses from green roofs and green roof media capacity for neutralizing acid rain*. Final Report. National Decentralized Water Resource Capacity Development Project Research Project. Pennsylvania State University.

Clark, S., B. Long, C. Siu, J. Spicher and K. Steele. 2008. “Early-life runoff quality: green versus traditional roofs.” *Low Impact Development 2008.* Seattle, WA. American Society of Civil Engineers.

Dunnett, N. and N. Kingsbury. 2004. *Planting Green Roofs and Living Walls*. Timber Press. Portland, Oregon.

Maryland Department of Environment. (MDE). 2008. *Chapter 5. Environmental Site Design.* “Green Roofs.” Baltimore, MD.

Miller, C. 2008. *Green roofs as stormwater best management practices: Preliminary computation of runoff coefficients: sample analysis in the Mid-Atlantic states*. Roofscapes, Inc. Philadelphia, PA.

Moran, A., W. Hunt and G. Jennings. 2004. *Green roof research of stormwater runoff quantity and quality in North Carolina*. NWQEP Notes. No. 114. North Carolina State University. Raleigh, NC.

North Carolina State University (NCSU). 2008. *Green Roof Research Web Page*. Department of Biological and Agricultural Engineering. http://www.bae.ncsu.edu/greenroofs .

Northern Virginia Regional Commission (NVRC). 2007. *Low Impact Development Manual.* “Vegetated Roofs.” Fairfax, VA.

Schueler et al 2007. *Urban Stormwater Retrofit Practices*. Manual 3 in the Urban Subwatershed Restoration Manual Series. Center for Watershed Protection. Ellicott City, MD.

Snodgrass, E. and L. Snodgrass. 2006. *Green Roof Plants: a resource and planting guide*. Timber Press. Portland, OR.

Van Woert, N., D. Rowe, A. Andersen, C. Rugh, T. Fernandez and L. Xiao. 2005. “Green roof stormwater retention: effects of roof surface, slope, and media depth.” *Journal of Environmental Quality*. 34: 1036-1044.

Weiler, S. and K. Scholz-Barth 2009. *Green Roof Systems: A Guide to the Planning, Design, and Construction of Landscapes over Structure.* Wiley Press. New York, NY.

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 6

RAINWATER HARVESTING

VERSION 1.9.5
March 1, 2011

SECTION 1: DESCRIPTION

Rainwater harvesting systems intercept, divert, store and release rainfall for future use. The term rainwater harvesting is used in this specification, but it is also known as a cistern or rainwater harvesting system. Rainwater that falls on a rooftop is collected and conveyed into an above- or below-ground storage tank where it can be used for non-potable water uses and on-site stormwater disposal/infiltration. Non-potable uses may include flushing of toilets and urinals inside buildings, landscape irrigation, exterior washing (e.g. car washes, building facades, sidewalks, street sweepers, fire trucks, etc.), fire suppression (sprinkler) systems, supply for chilled water cooling towers, replenishing and operation of water features and water fountains, and laundry, if approved by the local authority. Replenishing of pools may be acceptable if special measures are taken, as approved by the appropriate regulatory authority.

In many instances, rainwater harvesting can be combined with a secondary (down-gradient) runoff reduction practice to enhance runoff volume reduction rates and/or provide treatment of overflow from the rainwater harvesting system. Some candidate secondary practices include:

- Rooftop Disconnection: Design Specification No. 1 (excluding rain tanks and cisterns). This may include release to a compost-amended filter path
- Sheet Flow to a Vegetated Filter Strip or Conserved Open Space: Design Specification No. 2
- Grass Channel: Design Specification No. 3
- Infiltration and Micro-Infiltration: Design Specification No. 8
- Micro-Bioretention (rain garden): Design Specification No. 9
- Storage and release in a foundation planter (Urban Bioretention – Stormwater Design Specification No. 9, Appendix 9-A)
- Dry Swale**:** Design Specification No. 10
- Underground infiltration soak-away pit (see explanation on **page 14**).

Section 5.3 (Physical Feasibility & Design Applications) provides more detail on system configurations, including the use of secondary practices.

In addition, the actual runoff reduction rates for rainwater harvesting systems are "user defined," based on tank size, configuration, demand drawdown, and use of secondary practices. A Cistern Design Spreadsheet (CDS) is provided as a companion to this specification, and is discussed in more detail in **Section 6** (Design Criteria).

SECTION 2: PERFORMANCE

The overall stormwater functions of the rainwater harvesting systems are described in **Table 6.1**.

Table 6.1: Summary of Stormwater Functions Provided by Rainwater Harvesting

Stormwater Function	Performance
Annual Runoff Volume Reduction (RR)	Variable up to 90% [2]
Total Phosphorus (TN) EMC Reduction[1] by BMP Treatment Process	0%
Total Phosphorus (TN) Mass Load Removal	Variable up to 90% [2]
Total Nitrogen (TN) EMC Reduction[1] by BMP Treatment Process	0%
Total Nitrogen (TN) Mass Load Removal	Variable up to 90% [2]
Channel Protection	Partial: reduced curve numbers and increased Time of Concentration
Flood Mitigation	Partial: reduced curve numbers and increased Time of Concentration
[1] Nutrient mass removal is equal to the runoff reduction rate. Zero additional removal rate is applied to the rainwater harvesting system only. Nutrient removal rates for secondary practices will be in accordance with the design criteria for those practice. [2] Credit is variable and determined using the Cistern Design Spreadsheet. Credit up to 90% is possible if all water from storms with rainfall of 1 inch or less is used through demand, and the tank is sized such that no overflow from this size event occurs. The total credit may not exceed 90%.	

SECTION 3: DESIGN TABLE

Rainwater harvesting system design does not have a Level 1 and Level 2 design table. Runoff reduction credits are based on the total amount of annual internal water reuse, outdoor water reuse, and tank dewatering discharge calculated to be achieved by the tank system using the Cistern Design Spreadsheet.

SECTION 4: TYPICAL DETAILS

Figures 6.1 through 6.6 of **Section 5.3** provide typical schematics of cistern and piping system configurations, based on the design objectives (year-round internal use, external seasonal irrigation, etc.).

Figures 6.7 through 6.9 of **Section 5.4** provide typical schematics of Cistern tank configurations, based on the desired Treatment Volume and stormwater management objectives (Treatment Volume only, channel protection, etc.).

SECTION 5: PHYSICAL FEASIBILITY & DESIGN APPLICATIONS

A number of site-specific features influence how rainwater harvesting systems are designed and/or utilized. These should not be considered comprehensive and conclusive considerations, but rather some recommendations that should be considered during the process of planning to incorporate rainwater harvesting systems into the site design. The following are key considerations.

5.1 Site Conditions

Available Space. Adequate space is needed to house the tank and any overflow. Space limitations are rarely a concern with rainwater harvesting systems if they are considered during the initial building design and site layout of a residential or commercial development. Storage tanks can be placed underground, indoors, on rooftops or within buildings that are structurally designed to support the added weight, and adjacent to buildings. Designers can work with Architects and Landscape Architects to creatively site the tanks. Underground utilities or other obstructions should always be identified prior to final determination of the tank location.

Site Topography. Site topography and tank location should be considered as they relate to all of the inlet and outlet invert elevations in the rainwater harvesting system. The total elevation drop will be realized beginning from the downspout leaders to the final mechanism receiving gravity-fed discharge and/or overflow from the cistern.

These elevation drops will occur along the sloping lengths of the underground roof drains from roof drain leader downspouts at the building all the way to the cistern. A vertical drop occurs within the filter before the cistern. The cistern itself must be located sufficiently below grade and below the frost line, resulting in an additional elevation drop. When the cistern is used for additional volume detention for channel and/or flood protection, an orifice may be included with a low invert specified by the designer. An overflow will always be present within the system, with an associated invert. Both the orifice (if specified) and the overflow will drain the tank during large storms, routing this water through an outlet pipe, the length and slope of which will vary from one site to another.

All these components of the rainwater harvesting system have an elevation drop associated with them. The final invert of the outlet pipe must match the invert of the receiving mechanism (natural channel, storm drain system, etc.) that receives this overflow. These elevation drops and associated inverts should be considered early in the design, in order to ensure that the rainwater harvesting system is feasible for the particular site.

Site topography and tank location will also affect the amount of pumping needed. Locating storage tanks in low areas will make it easier to route roof drains from buildings to cisterns. However, it will increase the amount of pumping needed to distribute the harvested rainwater back into the building or to irrigated areas situated on higher ground. Conversely, placing storage tanks at higher elevations may require larger diameter roof drains with smaller slopes. However, this will also reduce the amount of pumping needed for distribution. In general, it is often best to locate the cistern close to the building, ensuring that minimum roof drain slopes and enclosure of roof drain pipes are sufficient.

Available Hydraulic Head. The required hydraulic head depends on the intended use of the water. For residential landscaping uses, the cistern should be sited up-gradient of the landscaping areas or on a raised stand. Pumps are commonly used to convey stored rainwater to the end use in order to provide the required head. When the water is being routed from the cistern to the inside of a building for non-potable use, often a pump is used to feed a much smaller pressure tank inside the building which then serves the internal demands through gravity-fed head. Cisterns can also use gravity- to accomplish indoor residential uses (e.g., laundry) that do not require high water pressure. In cases where cisterns are located on building roofs in order to operate under gravity-fed conditions, the structure must be designed to provide for the added weight of the rainwater harvesting system and stored water.

Water Table. Underground storage tanks are most appropriate in areas where the tank can be buried *above* the water table. The tank should be located in a manner that will not subject it to flooding. In areas where the tank is to be buried partially below the water table, special design features must be employed, such as sufficiently securing the tank (to keep it from “floating”), conducting buoyancy calculations when the tank is empty, etc. The tank may need to be secured appropriately with fasteners or weighted to avoid uplift buoyancy. The tank must also be installed according to the tank manufacturer’s specifications.

Soils. Storage tanks should only be placed on native soils or on fill in accordance with the manufacturer's guidelines. The bearing capacity of the soil upon which the cistern will be placed should be considered, as full cisterns can be very heavy. This is particularly important for above-ground cisterns, as significant settling could cause the cistern to lean or in some cases to potentially topple. A sufficient aggregate, or concrete base, may be appropriate depending on the soils. The pH of the soil should also be considered in relation to its interaction with the cistern material.

Proximity of Underground Utilities. All underground utilities must be taken into consideration during the design of underground rainwater harvesting systems, treating all of the rainwater harvesting system components and storm drains as typical stormwater facilities and pipes. The underground utilities must be marked and avoided during the installation of underground tanks and piping associated with the system. Appropriate minimum setbacks from septic drainfields should be observed, as specified by Virginia law and regulations.

Contributing Drainage Area. The contributing drainage area (CDA) to the cistern is the impervious area draining to the tank. In general, only rooftop surfaces should be included in the CDA. Parking lots and other paved areas can be used in rare circumstances with appropriate treatment (oil/water separators) and approval of the locality. Areas of any size, including portions of roofs, can be used based on the sizing guidelines in this design specification. Runoff should be routed directly from rooftops to rainwater harvesting systems in closed roof drain systems or storm drain pipes, avoiding surface drainage, which could allow for increased contamination of the water.

Rooftop Material. The quality of the harvested rainwater will vary according to the roof material over which it flows. Water harvested from certain types of rooftops, such as asphalt sealcoats, tar and gravel, painted roofs, galvanized metal roofs, sheet metal or any material that may contain asbestos may leach trace metals and other toxic compounds. In general, harvesting rainwater from such roofs should be avoided, unless new information determines that these materials are sufficient for the intended use and are allowed by Virginia laws and regulations. If a sealant or paint roof surface is desired, it is recommended to use one that has been certified for such purposes by the National Sanitation Foundation (ANSI/NSF standard). The 2009 Virginia Rainwater Harvesting Manual and other references listed at the end of this specification describe the advantages and disadvantages of different roofing materials.

Water Quality of Rainwater. Designers should also note that the ***pH*** of rainfall in Virginia tends to be acidic (ranging from 4.5 to 5.0), which may result in leaching of metals from the roof surface, tank lining or water laterals to interior connections. Once rainfall leaves rooftop surfaces, pH levels tend to be slightly higher, ranging between 5.5 to 6.0. Limestone or other materials may be added in the tank to buffer acidity, if desired.

Hotspot Land Uses. Harvesting rainwater can be an effective method to prevent contamination of rooftop runoff that would result from mixing it with ground-level runoff from a stormwater hotspot operation. In some cases, however, industrial roof surfaces may also be designated as stormwater hotspots.

Setbacks from Buildings. Cistern overflow devices should be designed to avoid causing ponding or soil saturation within 10 feet of building foundations. Storage tanks should be designed to be watertight to prevent water damage when placed near building foundations. In general, it is recommended that underground tanks be set at least 10 feet from any building foundation.

Vehicle Loading. Whenever possible, underground rainwater harvesting systems should be placed in areas without vehicle traffic or be designed to support live loads from heavy trucks, a requirement that may significantly increase construction costs.

5.2 Stormwater Uses

The capture and reuse of rainwater can significantly reduce stormwater runoff volumes and pollutant loads. By providing a reliable and renewable source of water to end users, rainwater harvesting systems can also have environmental and economic benefits beyond stormwater management (e.g., increased water conservation, water supply during drought and mandatory municipal water supply restrictions, decreased demand on municipal or groundwater supply, decreased water costs for the end-user, potential for increased groundwater recharge, etc). To enhance their runoff reduction and nutrient removal capability, rainwater harvesting systems can be combined with other rooftop disconnection practices, such as micro-infiltration practices (Stormwater Design Specification No. 8) and rain gardens or foundation planters (Stormwater Design Specification No. 9). In this specification, these allied practices are referred to as "secondary runoff reduction practices."

While the most common uses of captured rainwater are for non-potable purposes, such as those noted above, in some limited cases rainwater can be treated to potable standards. This assumes that (1) the treatment methods and end use quality meet drinking water standards and regulations, and (2) the harvesting system is approved by the Health Department and the local governing authority. Treating harvested water to potable standards may drive up installation and maintenance costs significantly.

5.3 Design Objectives and System Configurations

Many rainwater harvesting system variations can be designed to meet user demand and stormwater objectives. This specification focuses on providing a design framework for addressing the water quality treatment volume (T_v) credit objectives and achieving compliance with the regulations. From a rainwater harvesting standpoint, there are numerous potential configurations that could be implemented. However, in terms of the goal of addressing the design treatment volume, this specification adheres to the following concepts in order to properly meet the stormwater volume reduction goals:

- Credit is only available for dedicated year-round drawdown/demand for the water. While seasonal practices (such as irrigation) may be incorporated into the site design, they are not considered to contribute to the treatment volume credit (for stormwater purposes) unless a drawdown at an equal or greater rate is also realized during non-seasonal periods (e.g. treatment in a secondary runoff reduction practice during non-irrigation months).
- System design is encouraged to use rainwater as a resource to meet on-site demand or in conjunction with other runoff reduction practices (especially those that promote groundwater recharge).
- Pollutant load reduction is realized through reduction of the volume of runoff leaving the site.
- Peak flow reduction is realized through reduced volume and temporary storage of runoff.

Therefore, the rainwater harvesting system design configurations presented in this specification are targeted for continuous (year-round) use of rainwater through (1) internal use, and (2) irrigation and/or treatment in a secondary practice. Three basic system configurations are described below.

Configuration 1: Year-round indoor use with optional seasonal outdoor use (Figure 6.1). The first configuration is for year round indoor use along with optional seasonal outdoor use, such as irrigation. Because there is no on-site secondary runoff reduction practice incorporated into the design for non-seasonal (or non-irrigation) months, the system must be designed and treatment credit awarded for the interior use only. (However, it should be noted that the seasonal irrigation will provide an economic benefit in terms of water usage). Stormwater credit can be enhanced by adding a secondary runoff reduction practice (see Configuration 3 below).

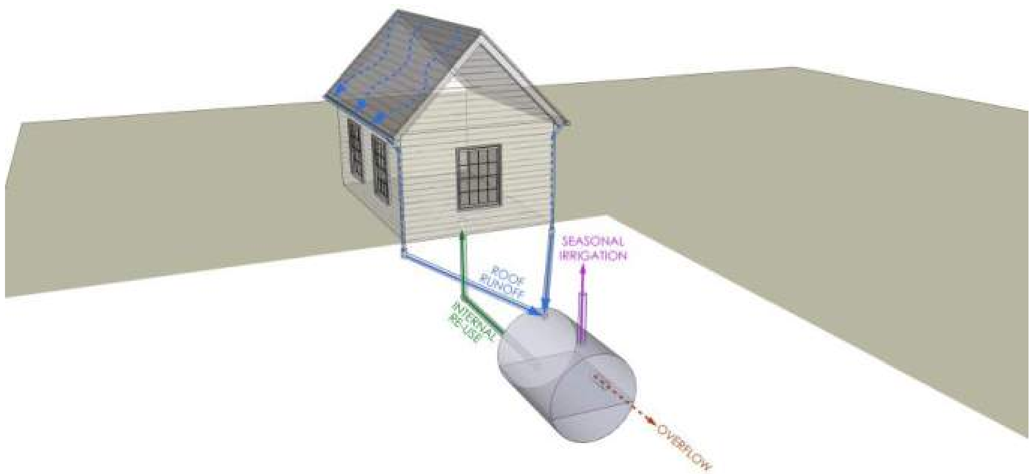


Figure 6.1. Configuration 1: Year-round indoor use with optional seasonal outdoor use

Configuration 2: Seasonal outdoor use and approved year-round secondary runoff reduction practice (Figure 6.2). The second configuration uses stored rainwater to meet a seasonal or intermittent water use, such as irrigation. However, because these uses are only intermittent or seasonal, this configuration also relies on an approved secondary practice for stormwater credit. Compared to a stand-alone BMP (without the upgradient tank), the size and/or storage volume of the secondary practice can be reduced based on the storage in the tank. The tank's drawdown and release rate should be designed based on the infiltration properties, surface area, and capacity of the receiving secondary runoff reduction practice. The release rate therefore is typically much less than the flow rate that would result from routing a detention facility. The secondary practice should serve as a "backup" facility, especially during non-irrigation months. In this regard, the tank should provide some meaningful level of storage and reuse, accompanied by a small flow to the secondary practice. This is especially important if the size and/or storage volume of the secondary practice is reduced compared to using that practice in a "stand-alone" design (i.e., without an upgradient cistern). See Section 5.4 -- Tank Design 3 -- for more information.

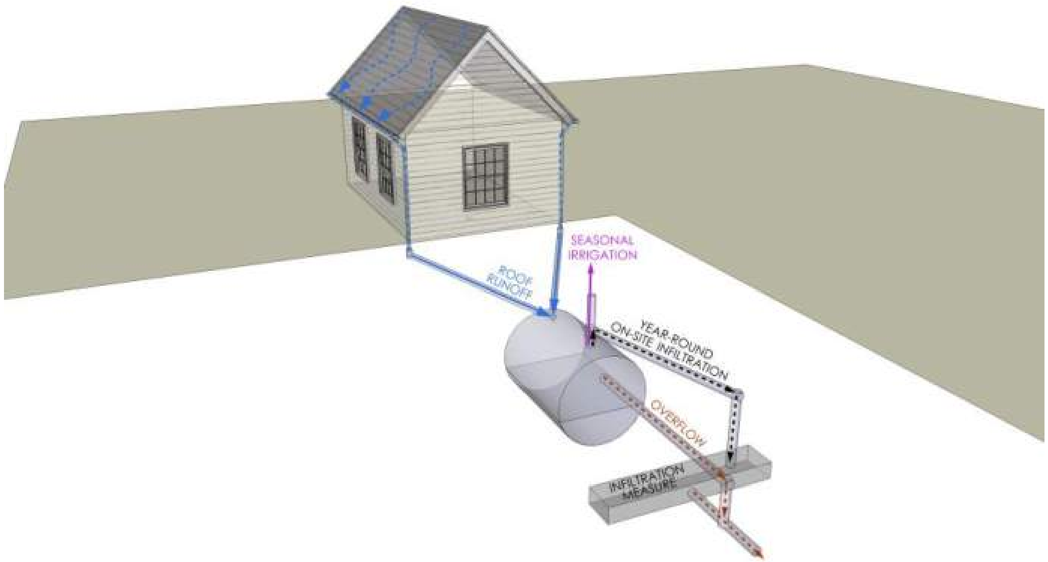


Figure 6.2. Configuration 2: Seasonal outdoor use and approved year-round secondary practice

Configuration 3: Year-round indoor use, seasonal outdoor irrigation, and non-seasonal treatment in a secondary runoff reduction practice (Figure 6.3). The third configuration provides for a year-round internal non-potable water demand, and a seasonal outdoor, automated irrigation system demand. In addition, this configuration incorporates a secondary practice during non-irrigation (or non-seasonal) months in order to yield a greater stormwater credit. In this case, the drawdown due to seasonal irrigation must be compared to the drawdown due to water released to the secondary practice. The minimum of these two values is used for system modeling and stormwater credit purposes.

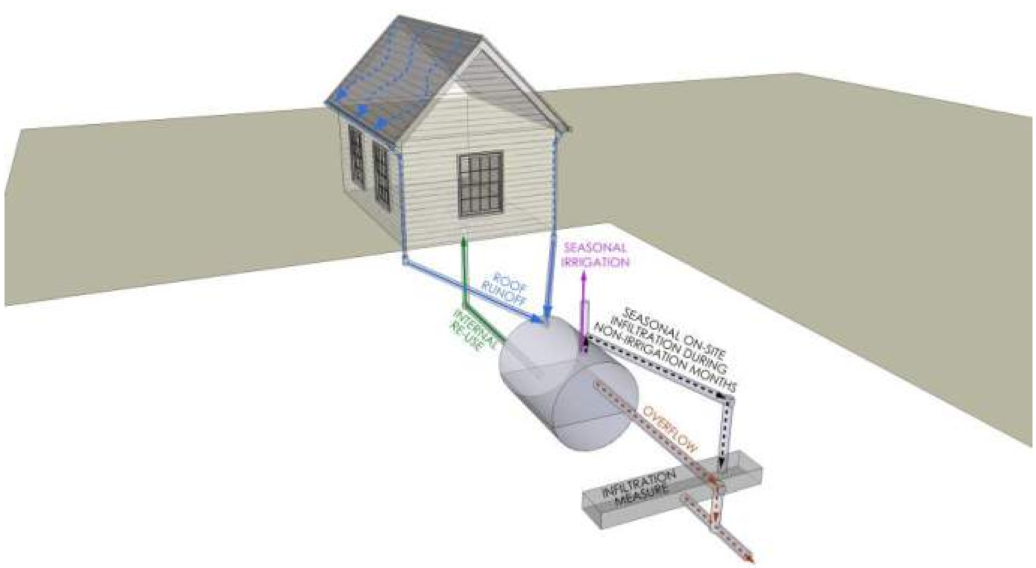


Figure 6.3. Configuration 3: Year-round indoor use, seasonal outdoor irrigation, and non-seasonal on-site treatment in secondary practice

5.4 Design Objectives and Tank Design Set-Ups

Pre-fabricated rainwater harvesting cisterns typically range in size from 250 to over 30,000 gallons. There are three basic tank design configurations used to meet the various rainwater harvesting system configurations that are described in **Section 5.3**.

Tank Design 1. The first tank set-up (**Figure 6.4**) maximizes the available storage volume associated with the Treatment Volume (T_v) to meet the desired level of Treatment Credit. This layout also maximizes the storage that can be used to meet a demand. An emergency overflow exists near the top of the tank as the only gravity release outlet device (not including the pump, manway or inlets). It should be noted that it is possible to address channel and flood protection volumes with this tank configuration, but the primary purpose is to address the water quality T_v.

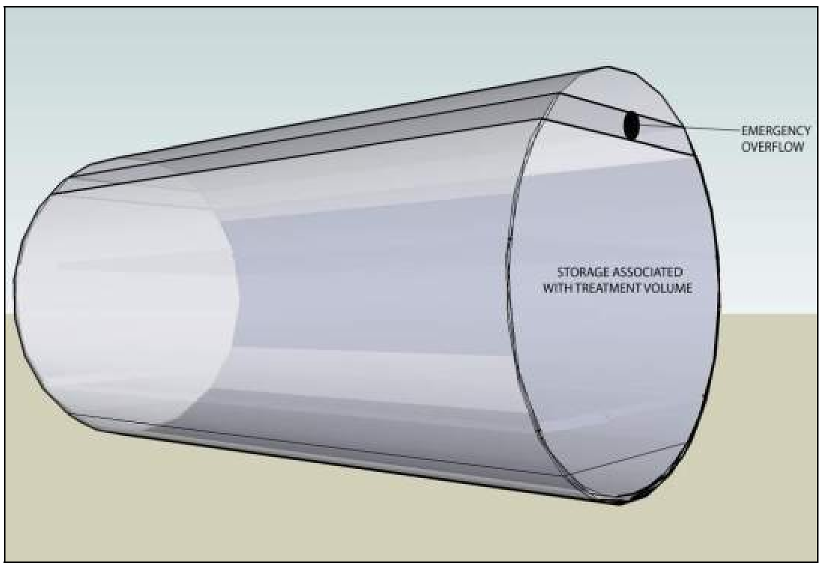


Figure 6.4. Tank Design 1: Storage Associated with Treatment Volume (Tv) only

Tank Design 2. The second tank set-up (**Figure 6.5**) uses tank storage to meet the Treatment Volume (T_v) objectives as well as using an additional detention volume above the treatment volume space to also meet some or all of the channel and/or flood protection volume requirements. An orifice outlet is provided at the top of the design storage for the T_v storage level, and an emergency overflow is located at the top of the detention volume level. This specification only addresses the storage for the T_v. However, in combination with other approved hydrologic routing programs, the Runoff Reduction spreadsheet may be used to model and size the Channel Protection and Flood Protection (detention) volumes.

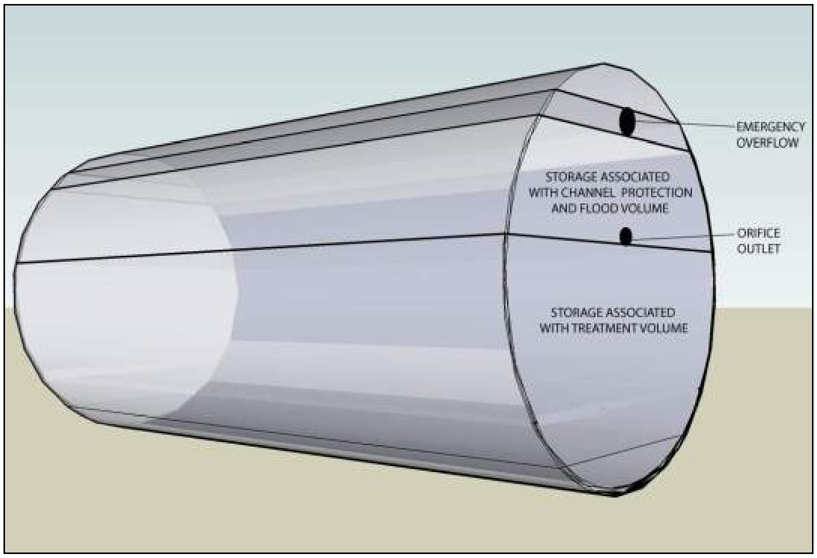


Figure 6.5. Tank Design 2: Storage Associated with Treatment, Channel Protection and Flood Volume

Tank Design 3. The third tank set-up (**Figure 6.6**) creates a constant drawdown within the system. The small orifice at the bottom of the tank needs to be routed to an appropriately designed secondary practice (e.g., rain garden, micro-scale infiltration, urban bioretention, etc.) that will allow the rainwater to be treated and allow for groundwater recharge over time. The release should not be discharged to a receiving channel or storm drain without treatment, and maximum specified drawdown rates from this constant drawdown should be adhered to, since the primary function of the system is not intended to be detention.

For the purposes of this tank design, the secondary practice must be considered a component of the rainwater harvesting system with regard to the runoff reduction percentage calculated in the Runoff Reduction Spreadsheet. In other words, the runoff reduction associated with the secondary practice must not be added (or double-counted) to the rainwater harvesting percentage. The reason for this is that the secondary practice is an integral part of a rainwater harvesting system with a constant drawdown. The exception to this would be if the secondary practice were also sized to capture and treat impervious and/or turf area beyond the area treated by rainwater harvesting (for instance, the adjacent yard or a driveway). In this case, only these additional areas should be added into the Runoff Reduction Spreadsheet to receive credit for the secondary practice.

While a small orifice is shown at the bottom of the tank in **Figure 6.6**, the orifice could be replaced with a pump that would serve the same purpose, conveying a limited amount of water to a secondary practice on a routine basis.

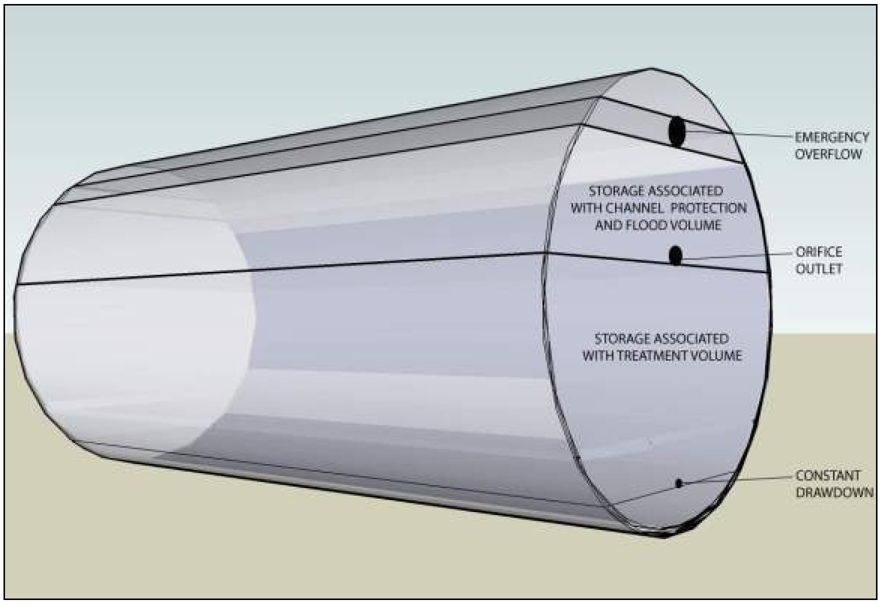


Figure 6.6. Tank Design 3: Constant drawdown, Storage Associated with Treatment, Channel Protection and Flood Volume

5.5. On-Site Treatment in a Secondary Practice

Recent rainwater harvesting system design materials do not include guidance for on-site stormwater infiltration or "disposal". The basic approach is to provide a dedicated secondary runoff reduction practice on-site that will ensure water within the tank will gradually drawdown at a specified design rate between storm events. Secondary runoff reduction practices may include the following:

- Rooftop Disconnection (Stormwater Design Specification No. 1), excluding rain tanks and cisterns. This may include release to a compost-amended filter path
- Vegetated filter strip (Stormwater Design Specification No. 2)
- Grass channel (Stormwater Design Specification No. 3)
- Infiltration and micro-infiltration (Stormwater Design Specification No. 8)
- Micro-bioretention (rain garden) (Stormwater Design Specification No. 9)
- Storage and release in foundation planter (Stormwater Design Spec No. 9, Appendix 9-A)
- Dry swale (Stormwater Design Specification No. 10)
- Underground infiltration soak-away pit (see the explanation below).

The secondary practice approach is useful to help achieve the desired treatment credit when demand is not enough to sufficiently draw water levels in the tank down between storm events. Of course, if demand for the harvested rainwater is relatively high, then a secondary practice may not be needed or desired.

While design specifications are available for most of the secondary practices proposed, an "*underground infiltration soak-away pit*" (or Infiltration facility, Stormwater Design Specification 8) may prove useful in some situations and may be used in conditions where the soil has moderate to high infiltration rates. The soak-away pit must be properly designed to adequately infiltrate the controlled design release rate. The design is subject to approval by the reviewing authority.

Use of a secondary practice may be particularly useful to employ in sites that use captured rainwater for irrigation during part of the year, but have no other use for the water during non-irrigation months. During non-irrigation months, credit cannot be realized unless on-site infiltration/treatment or another drawdown mechanism creates a year-round drawdown, since no stormwater benefit would be realized during non-seasonal periods.

The design of the secondary practice should account for soil types, ground surface areas, release rates, methods of conveyance (gravity fed or pumped), time periods of operation, and invert elevations to determine the disposal rate and sizing of the practice (both storage volume and surface area).

5.6 System Components

There are six primary components of a rainwater harvesting system (**Figure 6.7**):

- Roof surface
- Collection and conveyance system (e.g. gutter and downspouts)
- Pre-screening and first flush diverter
- Storage tank
- Distribution system
- Overflow, filter path or secondary runoff reduction practice

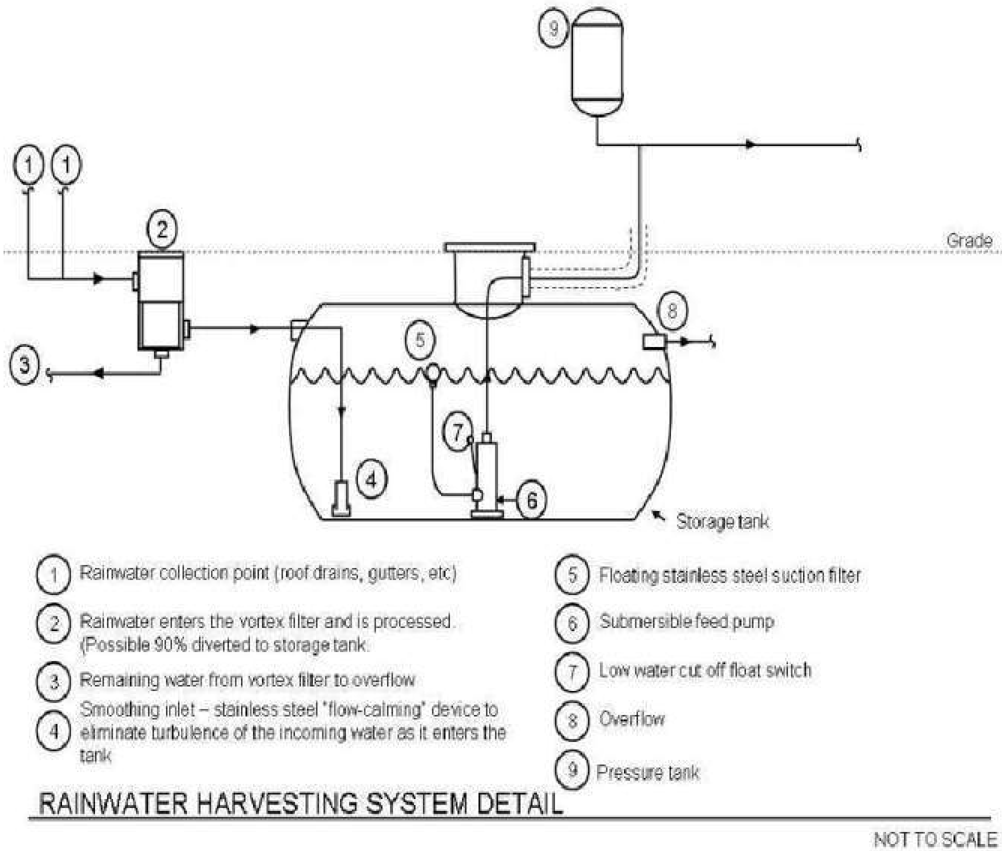


Figure 6.7. Sample Rainwater harvesting system System Detail

Each of these system components is discussed below.

Rooftop Surface. The rooftop should be made of smooth, non-porous material with efficient drainage either from a sloped roof or an efficient roof drain system. Slow drainage of the roof leads to poor rinsing and a prolonged first flush, which can decrease water quality. If the harvested rainwater will be used for potable uses, or uses with significant human exposure (e.g. pool filling, watering vegetable gardens), care should be taken in the choice of roof materials. Some materials may leach toxic chemicals making the water unsafe for humans. Rainwater can also be harvested from other impervious surfaces, such as parking lots and driveways; however, this practice is much less common and should be discouraged in general as it will require more extensive pretreatment or treatment, and will most likely increase maintenance since the quality of water is typically much lower.

Collection and Conveyance System. The collection and conveyance system consists of the gutters, downspouts and pipes that channel stormwater runoff into storage tanks. Gutters and downspouts should be designed as they would for a building without a rainwater harvesting system. Aluminum, round-bottom gutters and round downspouts are generally recommended for rainwater harvesting. Minimum slopes of gutters should be specified. At a minimum, gutters should be sized with slopes specified to contain the 1-inch storm at a rate of 1-inch/hour for treatment volume credit. If volume credit will also be sought for channel and flood protection, the gutters should be designed to convey the 2 and 10-year storm, using the appropriate 2 and 10 year storm intensities, specifying size and minimum slope. In all cases, gutters should be hung at a minimum of 0.5% for 2/3 of the length and at 1% for the remaining 1/3 of the length.

Pipes (connecting downspouts to the cistern tank) should be at a minimum slope of 1.5% and sized/designed to convey the intended design storm, as specified above. In some cases, a steeper slope and larger sizes may be recommended and/or necessary to convey the required runoff, depending on the design objective and design storm intensity. Gutters and downspouts should be kept clean and free of debris and rust.

Pre-Treatment: Screening, First Flush Diverters and Filter Efficiencies. Pre-filtration is required to keep sediment, leaves, contaminants and other debris from the system. Leaf screens and gutter guards meet the minimal requirement for pre-filtration of small systems, although direct water filtration is preferred. All pre-filtration devices should be low-maintenance or maintenance-free. The purpose of pre-filtration is to significantly cut down on maintenance by preventing organic buildup in the tank, thereby decreasing microbial food sources.

For larger tank systems, the initial first flush must be diverted from the system before rainwater enters the storage tank. Designers should note that the term “first flush” in rainwater harvesting design does not have the same meaning as has been applied historically in the design of stormwater treatment practices. In this specification, the term “first flush diversion” is used to distinguish it from the traditional stormwater management term “first flush”. The amount can range between the first 0.02 to 0.06 inches of rooftop runoff.

The diverted flows (first flush diversion and overflow from the filter) must be directed to an acceptable pervious flow path that will not cause erosion during a 2-year storm or to an appropriate BMP on the property, for infiltration. Preferably the diversion will be conveyed to the same secondary runoff reduction practice that is used to receive tank overflows.

Various first flush diverters are described below. In addition to the initial first flush diversion, filters have an associated efficiency curve that estimates the percentage of rooftop runoff that will be conveyed through the filter to the storage tank. If filters are not sized properly, a large portion of the rooftop runoff may be diverted and not conveyed to the tank at all. A design intensity of 1-inch/hour should be used for the purposes of sizing pre-tank conveyance and filter components. This design intensity captures a significant portion of the total rainfall during a large majority of rainfall events (NOAA 2004). If the system will be used for channel and flood protection, the 2 and 10 year storm intensities should be used for the design of the conveyance and pre-treatment portion of the system. For the 1-inch storm treatment volume, a minimum of 95% filter efficiency is required. This efficiency includes the first flush diversion. The Cistern Design Spreadsheet, discussed more in **Section 6**, assumes a filter efficiency rate of 95% for the 1-inch storm. For the 2 and 10 year storms, a minimum filter efficiency of 90% should be met.

- ***First Flush Diverters.*** First flush diverters direct the initial pulse of stormwater runoff away from the storage tank. While leaf screens effectively remove larger debris such as leaves, twigs and blooms from harvested rainwater, first flush diverters can be used to remove smaller contaminants such as dust, pollen and bird and rodent feces (**Figure 6.8**). Simple first flush diverters require active management, by draining the first flush water volume to a pervious area following each rainstorm. First flush diverters may be the preferred pre-treatment method if the water is to be used for indoor purposes. A vortex filter (see below) may serve as an effective pre-tank filtration device and first flush diverter.

- ***Leaf Screens.*** Leaf screens are mesh screens installed over either the gutter or downspout to separate leaves and other large debris from rooftop runoff. Leaf screens must be regularly cleaned to be effective; if not maintained, they can become clogged and prevent rainwater from flowing into the storage tanks. Built-up debris can also harbor bacterial growth within gutters or downspouts (TWDB, 2005).

- ***Roof Washers.*** Roof washers are placed just ahead of storage tanks and are used to filter small debris from harvested rainwater (**Figure 6.9**). Roof washers consist of a tank, usually between 25 and 50 gallons in size, with leaf strainers and a filter with openings as small as 30-microns (TWDB, 2005). The filter functions to remove very small particulate matter from harvested rainwater. All roof washers must be cleaned on a regular basis.

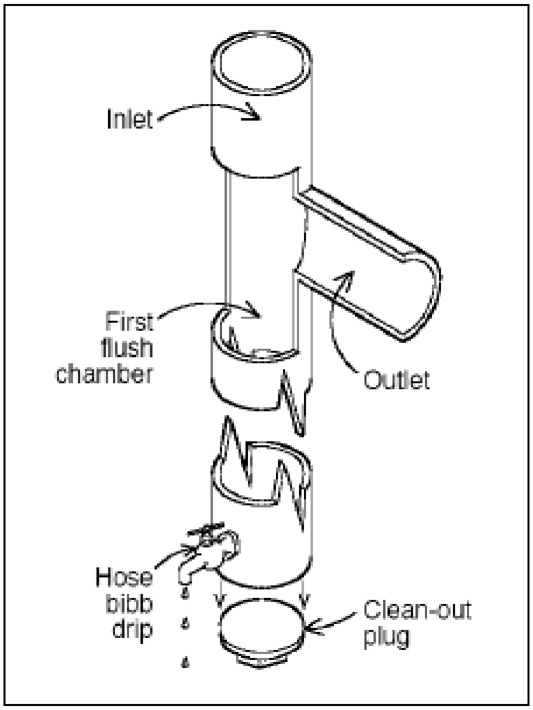


Figure 6.8. First Flush Diverter

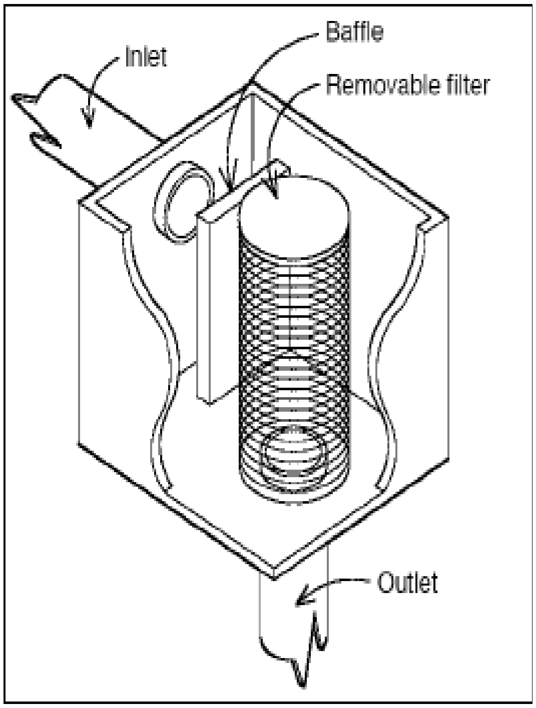


Figure 6.9. Roof Washer

- ***Vortex Filters.*** For large scale applications, vortex filters can provide filtering of rooftop rainwater from larger rooftop areas. Two images of the vortex filter are displayed below. The first image (**Figure 6.10**) provides a plan view photograph showing the interior of the filter with the top off. The second image (**Figure 6.11**) displays the filter just installed in the field prior to the backfill.

Figure 6.10. Interior of Vortex Filter

Figure 6.11. Installation of Vortex Filter prior to backfill

Storage Tanks. The storage tank is the most important and typically the most expensive component of a rainwater harvesting system. Cistern capacities range from 250 to over 30,000 gallons. Multiple tanks can be placed adjacent to each other and connected with pipes to balance water levels and increase overall storage on-site as needed. Typical rainwater harvesting system capacities for residential use range from 1,500 to 5,000 gallons. Storage tank volumes are calculated to meet the water demand and stormwater treatment volume credit objectives, as described in **Section 6** of this specification.

While many of the graphics and photos in this specification depict cisterns with a cylindrical shape, the tanks can be made of many materials and configured in various shapes, depending on the type used and the site conditions where the tanks will be installed. For example, configurations can be rectangular, L-shaped, or step vertically to match the topography of a site. The following factors that should be considered when designing a rainwater harvesting system and selecting a storage tank:

- Aboveground storage tanks should be UV and impact resistant.
- Underground storage tanks must be designed to support the overlying sediment and any other anticipated loads (e.g., vehicles, pedestrian traffic, etc.).
- Underground rainwater harvesting systems should have a standard size manhole or equivalent opening to allow access for cleaning, inspection, and maintenance purposes. This access point should be secured/locked to prevent unwanted access.
- All rainwater harvesting systems should be sealed using a water-safe, non-toxic substance.
- Rainwater harvesting systems may be ordered from a manufacturer or can be constructed on site from a variety of materials. **Table 6.2** below compares the advantages and disadvantages of different storage tank materials.
- Storage tanks should be opaque or otherwise protected from direct sunlight to inhibit algae growth and should be screened to discourage mosquito breeding and reproduction.
- Dead storage below the outlet to the distribution system and an air gap at the top of the tank should be added to the total volume. For gravity-fed systems, a minimum of 6 inches of dead storage should be provided. For systems using a pump, the dead storage depth will be based on the pump specifications.
- Any hookup to a municipal backup water supply should have a backflow prevention device to keep municipal water separate from stored rainwater; this may include incorporating an air gap to separate the two supplies. Local codes may have specifications for this.

Table 6.2. Advantages and Disadvantages of Various Cistern Materials

Tank Material	Advantages	Disadvantages
Fiberglass	Commercially available, alterable and moveable; durable with little maintenance; light weight; integral fittings (no leaks); broad application	Must be installed on smooth, solid, level footing; pressure proof for below-ground installation; expensive in smaller sizes
Polyethylene	Commercially available, alterable, moveable, affordable; available in wide range of sizes; can install above or below ground; little maintenance; broad application	Can be UV-degradable; must be painted or tinted for above-ground installations; pressure-proof for below-ground installation
Modular Storage	Can modify to topography; can alter footprint and create various shapes to fit site; relatively inexpensive	Longevity may be less than other materials; higher risk of puncturing of water tight membrane during construction
Plastic Barrels	Commercially available; inexpensive	Low storage capacity (20 to 50 gallons); limited application
Galvanized Steel	Commercially available, alterable and moveable; available in a range of sizes; film develops inside to prevent corrosion	Possible external corrosion and rust; must be lined for potable use; can only install above ground; soil pH may limit underground applications
Steel Drums	Commercially available, alterable and moveable	Small storage capacity; prone to corrosion, and rust can lead to leaching of metals; verify prior to reuse for toxics; water pH and soil pH may also limit applications
FerroConcrete	Durable and immoveable; suitable for above or below ground installations; neutralizes acid rain	Potential to crack and leak; expensive
Cast in Place Concrete	Durable, immoveable, versatile; suitable for above or below ground installations; neutralizes acid rain	Potential to crack and leak; permanent; will need to provide adequate platform and design for placement in clay soils
Stone or concrete Block	Durable and immoveable; keeps water cool in summer months	Difficult to maintain; expensive to build

Source: Cabell Brand, 2007, 2009

The images below in **Figures 6.12 to 6.14** display three examples of various materials and shapes of cisterns discussed in **Table 6.2** above.

Figure 6.12. Example of Multiple Fiberglass Cisterns in Series

Figure 6.13. Example of two Polyethylene Cisterns

Figure 6.14. Example of Modular Units

Distribution Systems. Most distribution systems require a pump to convey harvested rainwater from the storage tank to its final destination, whether inside the building, an automated irrigation system, or gradually discharged to a secondary runoff reduction practice. The rainwater harvesting system should be equipped with an appropriately-sized pump that produces sufficient pressure for all end-uses. The municipality may require the separate plumbing to be labeled as non-potable.

The typical pump and pressure tank arrangement consists of a multi-stage centrifugal pump, which draws water out of the storage tank and sends it into the pressure tank, where it is stored for distribution. When water is drawn out of the pressure tank, the pump activates to supply additional water to the distribution system. The backflow preventer is required to separate harvested rainwater from the main potable water distribution lines.

Distribution lines from the rainwater harvesting system should be buried beneath the frost line. Lines from the rainwater harvesting system to the building should have shut-off valves that are accessible when snow cover is present. A drain plug or cleanout sump, also draining to a pervious area, should be installed to allow the system to be completely emptied, if needed. Above-ground outdoor pipes should be insulated or heat-wrapped to prevent freezing and ensure uninterrupted operation during winter.

Overflow, Filter Path and Secondary Runoff Reduction Practice. An overflow mechanism should be included in the rainwater harvesting system design in order to handle an individual storm event or multiple storms in succession that exceed the capacity of the tank. Overflow pipes should have a capacity equal to or greater than the inflow pipe(s) and have a diameter and slope sufficient to drain the cistern while maintaining an adequate freeboard height. The overflow pipe should be screened to prevent access to the tank by rodents and birds.

The filter path is a pervious or grass corridor that extends from the overflow to the next runoff reduction practice, the street, an adequate existing or proposed channel, or the storm drain system. The filter path must be graded with a slope that results in sheet flow conditions. If compacted or impermeable soils are present along the filter path, compost amendments may be needed (see Stormwater Design Specification No. 4). It is also recommended that the filter path be used for first flush diversions.

In many cases, rainwater harvesting system overflows are directed to a secondary runoff reduction practice to boost overall runoff reduction rates. These options are addressed in **Section 5.5**.

SECTION 6: DESIGN CRITERIA

6.1. Sizing of Rainwater Harvesting Systems

The rainwater harvesting cistern sizing criteria presented in this section was developed using best estimates of indoor and outdoor water demand, long-term rainfall data, and rooftop capture area data, using a spreadsheet model (Forasté and Lawson, 2009). The Cistern Design Spreadsheet is primarily intended to provide guidance in sizing cisterns and to quantify the runoff reduction volume credit for input into the Runoff Reduction Spreadsheet for stormwater management compliance purposes. A secondary objective of the spreadsheet is to increase the beneficial uses of the stored stormwater, treating it as a valuable natural resource.

6.2. Incremental Design Volumes within Cistern

Rainwater tank sizing is determined by accounting for varying precipitation levels, captured rooftop runoff, first flush diversion (through filters) and filter efficiency, low water cut-off volume, dynamic water levels at the beginning of various storms, storage needed for treatment volume (permanent storage), storage needed for channel protection and flood volume (temporary detention storage), seasonal and year-round demand use and objectives, overflow volume, and freeboard volumes above high water levels during very large storms. See **Figure 6.15** for a graphical representation of these various incremental design volumes.

This specification does not provide design guidance for sizing the Channel and Flood Protection volume, but rather provides guidance on sizing for the 1-inch target storm Treatment Volume (T_V) Credit. See Chapter 10 ("Uniform Stormwater BMP Sizing Criteria") of the *Virginia Stormwater Management Handbook* (2010) for more information on design volumes and sizing criteria associated with various target storm events.

Note that the Treatment Volume is different from the "Storage Associated with the Treatment Volume". The Treatment Volume, as defined by DEQ in Table 10.2 of Chapter 10, is calculated by multiplying the "water quality" target rainfall depth (1 inch) with a composite of three site cover runoff coefficients (forest cover, disturbed soils/managed turf, and impervious cover). In the case of rainwater harvesting, because only rooftop surfaces are captured, only one runoff coefficient is applicable (impervious cover). Therefore, the only variable for Treatment Volume is surface area captured.

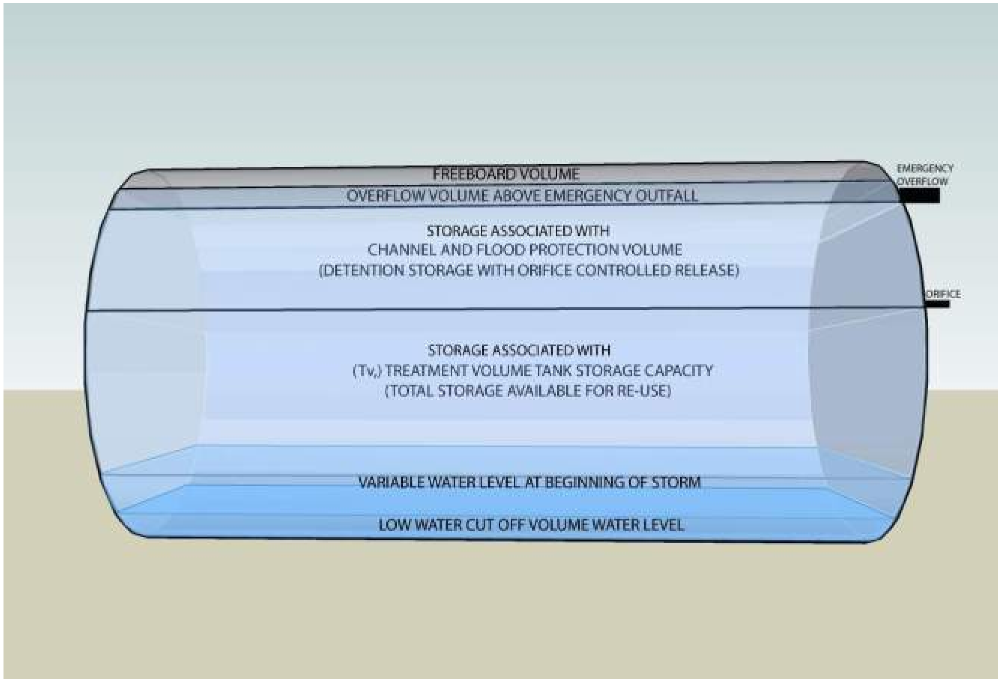


Figure 6.15. Incremental Design Volumes associated with tank sizing

The "Storage Associated with the Treatment Volume" is the storage within the tank that is modeled and available for reuse. While the Treatment Volume will remain the same for a specific rooftop capture area, the "Storage Associated with the Treatment Volume" may vary depending on demand and runoff reduction credit objectives. It includes the variable water level at the beginning of a storm and the low water cut-off volume that is necessary to satisfy pumping requirements.

6.3 Cistern Design Spreadsheet (CDS)

This specification is intimately linked with the Cistern Design Spreadsheet (CDS), which can be downloaded from the Virginia Stormwater BMP Clearinghouse web site at:

http://www.vwrrc.vt.edu/swc/NonProprietaryBMPs.html
(NOTE: The CDS is associated with this specification on that web page.)

The spreadsheet uses daily rainfall data from September 1, 1977 to September 30, 2007 to model performance parameters of the cistern under varying rooftop capture areas, demands on the system and tank size. The precipitation data is the same that was utilized by the Center for Watershed Protection (CWP) to determine the 90th percentile 1-inch water quality treatment volume target storm event, as presented and explained in Figure 10.1 in Chapter 10 of the Handbook. Precipitation data for four different regions throughout Virginia can be selected for use within the model.

- Richmond International Airport
- Reagan Airport (Alexandria)
- Lynchburg Regional Airport
- Millgap 2NNW (near Harrisonburg)

A runoff coefficient of 0.95 for rooftop surfaces and a filter efficiency rate of 95% for the 1-inch storm are assumed. It is assumed that filters are to be installed on all systems and that the first flush diversion is incorporated into the filter efficiency. The remaining precipitation is then added to the water level that existed in the cistern the previous day, with all of the total demands subtracted on a daily basis. If any overflow is realized, the volume is quantified and recorded. If the tank runs dry (reaches the cut-off volume level), then the volume in the tank is fixed at the low level and a dry-frequency day is recorded. The full or partial demand met in both cases is quantified and recorded. A summary of the water balance for the system is provided below.

Water Contribution:

- ***Precipitation to rooftop.*** The volume of water contributing to the rainwater harvesting system is a function of the rainfall and rooftop area captured, as defined by the designer.

- ***Municipal Backup (optional).*** In some cases, the designer may choose to install a municipal backup water supply to supplement tank levels. Note that municipal backups may also be connected post-tank (i.e. a connection is made to the non-potable water line that is used for pumping water from the tank for reuse), thereby not contributing any additional volume to the tank.

Water Losses:

- ***Rooftop Runoff Coefficient.*** The rooftop is estimated to convey 95% of the rainfall that lands on it's surface (i.e., $R_v = 0.95$).

- ***First Flush Diversion.*** The first 0.02 to 0.06 inch of rainfall that is directed to filters is diverted from the system in order to prevent clogging it with debris. This value is assumed to be contained within the filter efficiency rate.

- ***Filter Efficiency.*** Each filter has an efficiency curve associated with the rate of runoff and the size of the storm it will receive from a rooftop. It is assumed that, after the first flush diversion and loss of water due to filter inefficiencies, the remainder of the 1-inch storm will be successfully captured. This means that a minimum of 95% of the runoff from a 1-inch storm should be conveyed into the tank. The filter efficiency value is not adjustable at this time and cannot be modified as an input value in the CDS, but it should not be less than 95%. Some localities may require that a minimum filter efficiency for a larger storm event be met (e.g. minimum 90% filter efficiency for 2 or 10-year storm), depending on design objectives and local review agency policy. For the purposes of selecting an appropriately sized filter, a rainfall intensity of 1-inch/hour should be used for the 24 hour, 1-inch storm. The local rainfall intensity values for the 2 and 10 year storms should be used when designing for channel and flood protection volumes.

- ***Drawdown (Runoff Reduction Volume).*** This is the stored water within the cistern that is reused or directed to a secondary runoff reduction practice. It is the volume of runoff that is reduced from the rooftop drainage area. This is the water loss that translates into the Runoff Reduction Volume credit.

- ***Overflow.*** For the purposes of addressing treatment volume (not addressing channel or flood protections volumes), orifice outlets for both detention and emergency overflows are treated the same. This is the volume of water that may be lost during large storm events or successive precipitation events.

See **Appendix 6-A** for a detailed description of Spreadsheet Inputs.

6.4. Results for all Precipitation Events

The performance results of the rainwater harvesting system for all days during the entire period modeled, including the full spectrum of precipitation events, is included in the "Results" tab. This tab is not associated with determining the Runoff Reduction Volume Credit, but rather may be a useful tool in assisting the user to realize the performance of the various rainwater harvesting system sizes with the design parameters and demands specified.

- ***Demand Met.*** This is where the demand met for various size cisterns and rooftop area/demand scenarios is reported. A graph displaying the percentage of demand met for various cistern sizes is provided in this tab. Normally this graph assists the user in understanding the relationship between cistern sizes and optimal/diminishing returns. An example is provided below in **Figure 6.16**.

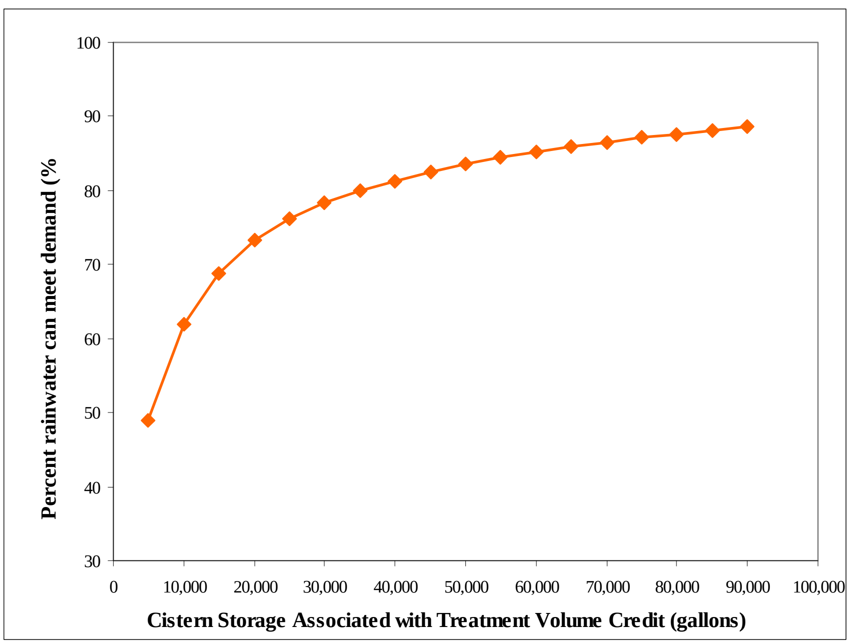


Figure 6.16. Percent Demand Met Vs. Storage for Re-use (Example)

At some point, larger cisterns no longer provide significant increases in percentages of demand met. Conversely, the curve informs the user when a small increase in cistern size can yield a significant increase in the percentage of time demand that is met.

- ***Dry Frequency.*** Another useful measure is the dry frequency. If the cistern is dry a substantial portion of the time, this measure can inform that user that he/she may want to decrease the size of the cistern, decrease the demand on the system or explore capturing more rooftop area to provide a larger supply, if feasible. It can also provide useful insight for the designer to determine whether he/she should incorporate a municipal backup supply to ensure sufficient water supply through the system at all times.

- ***Overflow Frequency.*** This is a metric of both overflow frequency and average volume per year for the full spectrum of rainfall events. This will inform the user regarding the design parameters and magnitude of demand and associated performance of the system. If the system overflows at a high frequency, then the designer may want to increase the size of the cistern, decrease the rooftop area captured, or consider other mechanisms that could increase drawdown (e.g. increase the area to be irrigated, incorporate or increase on-site infiltration, etc.).

- ***Inter-relationships and Curves of Diminishing Returns.*** Plotting various performance metrics against one another can be very informative and reveal relationships that are not evident otherwise. One such inter-relationship is the percentage of demand met versus tank size compared to the percentage of overflow frequency versus tank size, depicted on the same graph. A range of cistern sizes that tends to emerge, informing the designer where a small increase or decrease in tank size can have a significant impact on dry frequency and overflow frequency. Conversely, outside this range, changes in cistern sizes would yield small changes to dry frequency and overflow frequency, yet yield a large trade-off compared to the cost of the rainwater harvesting system.

6.5. Results for Precipitation Events of 1 Inch or Less

The amount of rooftop runoff volume that the tank can capture and use or draw down for all precipitation events of 1 inch or less is also quantified and recorded. These results are presented on the “Results Treatment Volume” tab. This information is used to calculate the Treatment Volume credit, which is used as an input to the Runoff Reduction spreadsheet.

- ***Treatment Volume Credit.*** A series of Treatment Volume credit values are calculated for multiple sizes of cisterns. A trade-off curve plots these results, which allows for a comparison of the credit earned versus cistern size. While smaller tanks may yield less credit than larger tanks, they are more cost-effective. Conversely, while larger tanks yield more credit, they are more costly. The curve assists the user to choose the appropriate tank size, based on the design objectives and site needs, as well as to understand the rate of diminishing returns.

- The Runoff Reduction and Treatment Volumes are also quantified; however, these results will automatically be calculated in a similar manner on the Runoff Reduction spreadsheet with the use of the Treatment Volume credit earned. Therefore, only the credit needs to be transferred, not the volumetric results.

- ***Overflow Volume from 1-inch storm.*** The frequency of cistern overflows and the average annual volume of the overflows resulting from precipitation events of 1-inch or less are also reported in this tab. A chart of the Treatment Volume Credit and Overflow Frequency for the 1-inch storm versus the storage volume is provided. An example is shown below in **Figure 6.17**.

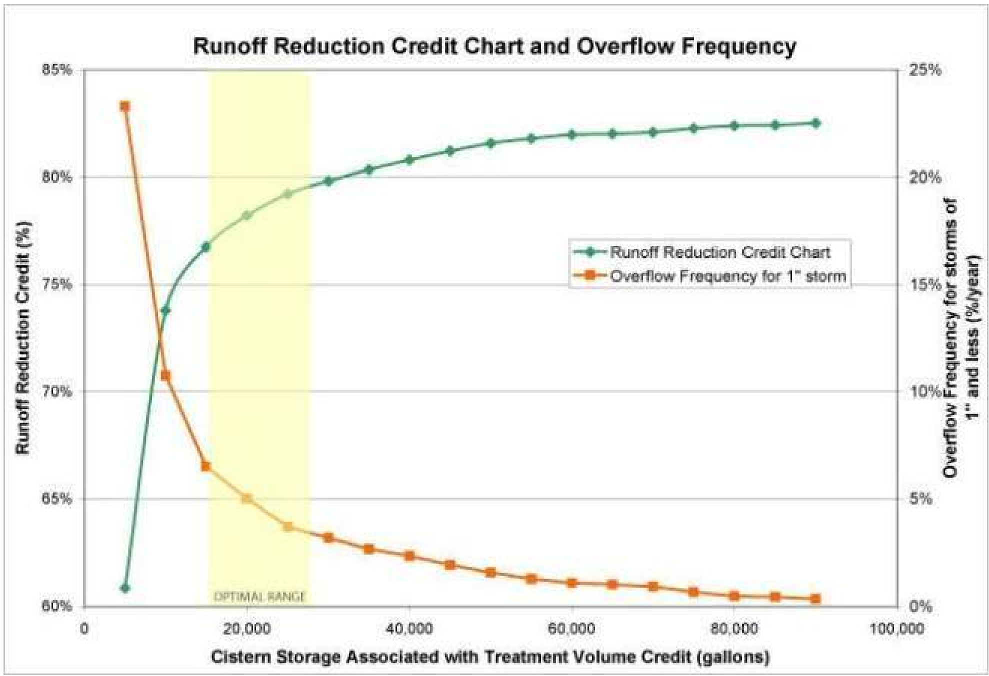


Figure 6.17. Percent Runoff Reduction Credit Vs. Storage for Re-use(Example)

These plotted results establish a trade-off relationship between these two performance metrics. In the above example, a 20,000 gallon cistern optimizes the runoff reduction credit and the overflow frequency (near the inflection point of both curves).

6.6. Results from Cistern Design Spreadsheet to be transferred to Runoff Reduction Spreadsheet

There are two results from this Cistern Design Spreadsheet that are to be transferred to the Runoff Reduction Spreadsheet, as follows:

1. <u>First Value to Transfer:</u> Once the cistern storage volume associated with the Runoff Reduction Volume credit has been selected, simply transfer that credit amount into the Runoff Reduction Spreadsheet column called “Credit” in the “2.f. To Rain Barrel, Rainwater harvesting system, Cistern” row in the blue cell (cell F30).

2. <u>Second Value to Transfer:</u> Then enter the rooftop area that was used in the Cistern Design Spreadsheet in the same row into the "Credit Area (acres)" column in the blue cell (cell G30).

See **Appendix 6-B** for STEP BY STEP INSTRUCTIONS for using the Cistern Design Spreadsheet.

6.7. Completing the Sizing Design of the Cistern

1. ***Low Water Cutoff Volume (Included).*** A dead storage area must be included **s**o that the pump will not run the tank dry. This volume is included within the Cistern Design Spreadsheet volume modeled.

2. ***Cistern Storage Associated with Treatment Volume (Included).*** This is the volume that was designed for using the Cistern Design Spreadsheet.

3. ***Adding Channel Protection and Flood Volumes (Optional).*** Additional detention volume may be added above and beyond the Cistern Storage Associated with the Treatment Volume for Channel Protection and Flood Volumes. Typical routing software programs may be used to design for this additional volume. The local reviewing authority has the option of accepting an adjusted curve number, accounting for the volume that has already been reduced as a result of the storage provided within the storage for the Treatment Volume (methodology as presented in the runoff reduction spreadsheet), or requiring that the system be modeled assuming that the Storage associated with the Treatment Volume is full.

4. ***Adding Overflow and Freeboard Volumes (Required).*** An additional volume above the emergency overflow must be provided in order for the tank to allow very large storms to pass. Above this overflow water level will be an associated freeboard volume. This volume must account for a minimum of 5% of the overall tank size; however, sufficient freeboard should be verified for large storms. These volumes need to be added to the overall size of the cistern tank.

Adding all of the incremental volumes above yields the total size of the cistern tank:

Total Cistern Size = 1 + 2 + 3 + 4

See **Appendix 6-C** for more notes relating to the use and development of the spreadsheet and documentation on the methodology used.

6.8. Design for Potable Water Calculations

In situations with insufficient potable water supply, rainwater can be treated and used for potable water supply subject to state and local health requirements (The Virginia Department of Health maintains regulations pertaining to reuse of water for potable uses). This rainwater harvesting system use is *not* covered in this specification, although there is growing interest in using harvested rainwater for potable drinking water. If this use is permitted by the appropriate public health authority, and the rainwater harvesting system is equipped with proper filtering equipment, the increased water reuse rate would sharply reduce the demand on municipal water systems sharply, resulting in commensurate cost savings. It would also enable a more standard plumbing system, since potable and non-potable water would no longer need to be separated.

6.9. Rainwater Harvesting Material Specifications

The basic material specifications for rainwater harvesting systems are presented in **Table 6.3**. Designers should consult with experienced rainwater harvesting system and irrigation installers on the choice of recommended manufacturers of prefabricated tanks and other system components.

Table 6.3. Design Specifications for Rainwater harvesting systems

Item	Specification
Gutters and Downspout	Materials commonly used for gutters and downspouts include polyvinylchloride (PVC) pipe, vinyl, aluminum and galvanized steel. Lead should not be used as gutter and downspout solder, since rainwater can dissolve the lead and contaminate the water supply. ▪ The length of gutters and downspouts is determined by the size and layout of the catchment and the location of the storage tanks. ▪ Be sure to include needed bends and tees.
Pre-Treatment	At least one of the following (all rainwater to pass through pre-treatment): ▪ first flush diverter ▪ vortex filter ▪ roof washer ▪ leaf and mosquito screen (1 mm mesh size)
Storage Tanks	▪ Materials used to construct storage tanks should be structurally sound. ▪ Tanks should be constructed in areas of the site where native soils can support the load associated with stored water. ▪ Storage tanks should be water tight and sealed using a water-safe, non-toxic substance. ▪ Tanks should be opaque to prevent the growth of algae. ▪ Re-used tanks should be fit for potable water or food-grade products. ▪ Underground rainwater harvesting systems should have a minimum of 18 to 24 inches of soil cover and be located below the frost line. ▪ The size of the rainwater harvesting system(s) is determined during the design calculations.
Note: This table does not address indoor systems or pumps.	

SECTION 7: REGIONAL & SPECIAL CASE DESIGN ADAPTATIONS

7.1. Karst Terrain

Above-ground rainwater harvesting systems are a preferred practice in karst, as long as the rooftop surface is not designated as a stormwater hotspot.

7.2. Coastal Plain

Above-ground rainwater harvesting systems are a preferred practice in the coastal plain, since they avoid the flat terrain, low head and high water table conditions that constrain other stormwater practices.

7.3. Steep Terrain

Rainwater harvesting systems are ideal in areas of steep terrain.

7.4. Cold Climate & Winter Performance

Rainwater harvesting systems have a number of components that can be impacted by freezing winter temperatures. Designers should give careful consideration to these conditions to prevent system damage and costly repairs.

For above-ground systems, winter-time operation may be more challenging, depending on tank size and whether heat tape is used on piping. If not protected from freezing, these rainwater harvesting systems must be taken offline for the winter and stormwater treatment credit may not be granted for the practice during that off-line period. At the start of the winter season, vulnerable above-ground systems that have not been designed to incorporate special precautions should be disconnected and drained. It may be possible to reconnect the former roof leader systems for the winter.

For underground and indoor systems, downspouts and overflow components should be checked for ice blockages during snowmelt events.

7.5. Linear Highway Sites

Rainwater harvesting systems are generally not applicable for linear highway sites**.**

SECTION 8: CONSTRUCTION

8.1. Construction Sequence

It is advisable to have a single contractor to install the rainwater harvesting system, outdoor irrigation system and secondary runoff reduction practices. The contractor should be familiar with rainwater harvesting system sizing, installation, and placement. A licensed plumber is required to install the rainwater harvesting system components to the plumbing system.

A standard construction sequence for proper rainwater harvesting system installation is provided below. This can be modified to reflect different rainwater harvesting system applications or expected site conditions.

- Choose the tank location on the site
- Route all downspouts or roof drains to pre-screening devices and first flush diverters
- Properly Install the tank
- Install the pump (if needed) and piping to end-uses (indoor, outdoor irrigation, or tank dewatering release)
- Route all pipes to the tank
- Stormwater should not be diverted to the rainwater harvesting system until the overflow filter path has been stabilized with vegetation.

8.2. Construction Inspection

The following items should be inspected prior to final sign-off and acceptance of a rainwater harvesting system:

- Rooftop area matches plans
- Diversion system is properly sized and installed
- Pretreatment system is installed
- Mosquito screens are installed on all openings
- Overflow device is directed as shown on plans
- Rainwater harvesting system foundation is constructed as shown on plans
- Catchment area and overflow area are stabilized
- Secondary runoff reduction practice(s) is installed as shown on plans

SECTION 9: MAINTENANCE

9.1. Maintenance Agreements

Section 4 VAC 50-60-124 of the regulations specifies the circumstances under which a maintenance agreement must be executed between the owner and the local program. This section sets forth inspection requirements, compliance procedures if maintenance is neglected, notification of the local program upon transfer of ownership, and right-of-entry for local program personnel.

All rainwater harvesting systems must be covered by a drainage easement to allow inspection and maintenance. The easement should include the tank, the filter path and any secondary runoff reduction practice. If the tank is located in a residential private lot, its existence and purpose must be noted on the deed of record. Homeowners will need to be provided a simple document that explains the purpose of the rainwater harvesting system and routine maintenance needs. Where legally binding maintenance agreements apply, they should specify the property owner's primary maintenance responsibility, require homeowners to pay to have their system inspected by a qualified third party inspector, and authorize the qualifying local program staff to access the property for inspection or corrective action in the event this is not done.

9.2. Maintenance Inspections

All rainwater harvesting systems components should be inspected by the property owner in the Spring and the Fall each year. A comprehensive inspection by a qualified third party inspector should occur every third year. An example maintenance inspection checklist for Rainwater Harvesting can be accessed in Appendix C of Chapter 9 of the *Virginia Stormwater Management Handbook* (2010).

9.3. Rainwater harvesting system Maintenance Schedule

Maintenance requirements for rainwater harvesting systems vary according to use. Systems that are used to provide supplemental irrigation water have relatively low maintenance requirements, while systems designed for indoor uses have much higher maintenance requirements. **Table 6.4** describes routine maintenance tasks to keep rainwater harvesting systems in working condition.

Table 6.4. Suggested Maintenance Tasks for Rainwater harvesting systems

Activity	Frequency
Keep gutters and downspouts free of leaves and other debris	O: Twice a year
Inspect and clean pre-screening devices and first flush diverters	O: Four times a year
Inspect and clean storage tank lids, paying special attention to vents and screens on inflow and outflow spigots. Check mosquito screens and patch holes or gaps immediately	O: Once a year
Inspect condition of overflow pipes, overflow filter path and/or secondary runoff reduction practices	O: Once a year
Inspect tank for sediment buildup	I: Every third year
Clear overhanging vegetation and trees over roof surface	I: Every third year
Check integrity of backflow preventer	I: Every third year
Inspect structural integrity of tank, pump, pipe and electrical system	I: Every third year
Replace damaged or defective system components	I: Every third year
Key: O = Owner I = qualified third party inspector	

SECTION 10: COMMUNITY & ENVIRONMENTAL CONCERNS

Although rainwater harvesting is an ancient practice, it is enjoying a revival due to the inherent quality of rainwater and the many beneficial uses that it can provide (TWDB, 2005). Some common concerns associated with rainwater harvesting that must be addressed during design include:

Winter Operation. Rainwater harvesting systems can be used throughout the year if they are located underground or indoors to prevent problems associated with freezing, ice formation and subsequent system damage. Alternately, an outdoor system can be used seasonally, or year round if special measures and design considerations are incorporated. See **Section 7.4** for further guidance on winter operation of rainwater harvesting systems.

Local Plumbing Codes. Designer and plan reviewers should consult local building codes to determine if they explicitly allow the use of harvested rainwater for toilet and urinal flushing. In the cases where a municipal backup supply is used, rainwater harvesting systems should be required to have backflow preventers or air gaps to keep harvested water separate from the main water supply. Pipes and spigots using rainwater must be clearly labeled as non-potable.

Mosquitoes. In some situations, poorly designed rainwater harvesting systems can create habitat suitable for mosquito breeding and reproduction. Designers should provide screens on above- and below-ground tanks to prevent mosquitoes and other insects from entering the tanks. If screening is not sufficient in deterring mosquitoes, dunks or pellets containing larvicide can be added to cisterns when water is intended for landscaping use.

Child Safety. Above-grade residential rainwater harvesting systems cannot have unsecured openings large enough for children to enter the tank. For underground cisterns, manhole access should be secured to prevent unwanted access.

SECTION 11: REFERENCES

Cabell Brand Center. 2009. *Virginia Rainwater Harvesting Manual, Version 2.0*. Salem, VA. (Draft Form) http://www.cabellbrandcenter.org

Cabell Brand Center. 2007. *Virginia Rainwater Harvesting Manual*. Salem, VA. http://www.cabellbrandcenter.org

Center for Watershed Protection (CWP). 2007. *Urban Stormwater Retrofit Practices.* Manual 3 in the Urban Subwatershed Restoration Manual Series. Ellicott City, MD.

City of Portland, Environmental Services. 2004. *Portland Stormwater Management Manual*. Portland, OR. http://www.portlandonline.com/bes/index.cfm?c=dfbcc

City of Tucson, AZ. 2005. *Water Harvesting Guidance Manual*. City of Tucson, AZ. Tucson, AZ.

Coombes, P. 2004. *Water Sensitive Design in the Sydney Region. Practice Note 4: Rainwater Tanks*. Published by the Water Sensitive Design in the Sydney Region Project. http://www.wsud.org/planning.htm

Credit Valley Conservation. 2008. *Credit River Stormwater Management Manual*. Mississauga, Ontario.

Forasté, J. Alex and Hirschman David. 2010. *A Methodology for using Rainwater Harvesting as a Stormwater Management BMP*. ASCE International Low Impact Development Conference, Redefining Water in the City. San Francisco, CA.

Forasté, J. Alex and Lawson, Sarah. 2009. *Cistern Design Spreadsheet*, McKee-Carson, Rainwater Management Systems, Inc., and Center for Watershed Protection, Inc.

Gowland, D. and T. Younos. 2008. *Feasibility of Rainwater Harvesting BMP for Stormwater Management*. Virginia Water Resources Research Center. Special Report SR38-2008. Blacksburg, VA.

National Oceanic and Atmospheric Administration (NOAA). 2004. *NOAA Atlas 14 Precipitation-Frequency Atlas of the United States, Volume 2, Version 3.0*. Revised 2006. Silver Spring, MD.

North Carolina Division of Water Quality. 2008. *Technical Guidance: Stormwater Treatment Credit for Rainwater Harvesting Systems*. Revised September 22, 2008. Raleigh, NC.

Northern Virginia Regional Commission. 2007. *Low Impact Development Supplement to the Northern Virginia BMP Handbook*. Fairfax, Virginia.

Schueler, T., D. Hirschman, M. Novotney and J. Zielinski. 2007. *Urban stormwater retrofit practices*. Manual 3 in the Urban Subwatershed Restoration Manual Series. Center for Watershed Protection, Ellicott City, MD.

Schueler, T. 2008. Technical Support for the Baywide Runoff Reduction Method. Chesapeake Stormwater Network. Baltimore, MD. www.chesapeakestormwater.net

APPENDIX 6-A

CISTERN DESIGN SPREADSHEET INPUTS

The spreadsheet model requires the following user inputs:

Regional location. Indicate the region that is closest to where the practice is being installed. Rainfall data associated with that region will automatically provide the relevant precipitation data for the design storm for that area.

Roof area. The user must estimate the total rooftop area that will be captured for contribution to the system; this combined with the target storm (1 inch of rainfall for the water quality Treatment Volume) yields the volume of rooftop runoff to be managed.

Irrigation use. The user must supply the total pervious area (in square feet) that will be irrigated; the spreadsheet will automatically calculate the demand based on a 1-inch per week watering during the appropriate season, unless the user specifies a different watering rate. The user can specify a start date and an end date in the year to specify the irrigation season (e.g., March 30 to September 1). If an on-site infiltration system is designed, the lesser drawdown rate (irrigation or on-site infiltration during the off-season) must be used to quantify the Treatment Volume credit.

Indoor use. The user then needs to define the parameters relating to indoor use of water; the spreadsheet will automatically calculate the demand according to the following criteria:

- Number of bedrooms – the user enters the number of bedrooms in the home. The spreadsheet uses the same approach that currently determines drainfield size by estimating the use required to accommodate 1.5 people per bedroom.
- Laundry use – the user selects either yes/no as to whether harvested rainwater will be used for laundry. The spreadsheet calculates laundry use as 1 load per person per week with an estimated water usage of 20 gallons per load (the upper end of use for Energy Star washers), with the number of people determined by the number of bedrooms selected.
- Toilet use – the user selects either yes/no about whether harvested rainwater will be used to flush toilets. The spreadsheet calculates use, based on a low flow toilet (1.2 gallons per flush) with three flushes per person per day, with the number of people determined by the number of bedrooms selected.
- Optional additional input – the user may enter an additional demand, such as bus or fire truck washing, street sweeper filling, etc.

Chilled Water Cooling Towers. The user may enter a quantity of water that will be needed for use in chilled water cooling towers.

Secondary Runoff Reduction Practice Drawdown. A cell is provided to enter an additional drawdown for secondary runoff reduction practices linked to the rainwater harvesting system. This rate will be specified by the designer and based on a practice that has been designed to properly accept and infiltrate, store, and/or treat this drawdown amount.

APPENDIX 6-B

STEP-BY-STEP INSTRUCTION FOR USING THE CISTERN DESIGN SPREADSHEET

TAB 1: INPUT

1. Select a Region in the drop down menu that is located closest to the proposed site.

2. Enter the rooftop area to be captured and routed to the cistern (square feet).

3. Enter the Irrigation data, as described in Appendix 6-A (Spreadsheet Inputs) of this design specification.

4. Enter the Indoor Demand – Flushing toilets/urinals, as described in Appendix 6-A.

5. Enter the Indoor Demand – Laundry, as described in Appendix 6-A.

6. Enter Additional Daily Uses (gallons per day).

7. Enter the amount that will be used for Chilled Water Cooling Towers (gallons per day).

8. Enter the On-Site infiltration design drawdown rate (gallons per day).

9. Enter the filter efficiency percentage for the 1-inch storm at a 1-inch/hour intensity. A minimum of 95% must be achieved and is assumed as the base value. However, if the filter achieves a higher efficiency rate, this higher value can be entered.

TAB 2: JULIAN DAY CALENDER

This tab is included for assistance in selecting a start date and end date for any demand practices. The day of the year should be selected according to the julian day dates specified in this tab.

TAB 3: RESULTS – TREATMENT VOLUME CREDIT

10. Select the Results – Treatment Volume Credit (TVC) tab to view modeling results for the 1-inch storm.

11. Observe the results for the Treatment Volume Credit highlighted in the green column, showing the dry frequency and the overflow frequency as they relate to the cistern storage associated with the TVC. If the TVC level is much higher or lower than design objectives for many of the cistern storage sizes, the input values should be assessed to determine if the demand can be increased or decreased.

TAB 4: RESULTS

12. Select the Results tab to view the modeling results for all storm events.

13. Observe the results for overflow frequency, dry frequency and percent of demand met by rainwater.

14. If the demand met for a particular storage size is adequate, observe the dry frequency, overflow frequency and TVC. If all of the design parameters meet design objectives and balance trade-offs reasonably well, move to the next step. If any of the resulting performance metrics are not acceptable design objectives, then re-visit the input spreadsheet to assess whether lower or higher demands can be achieved (e.g. decrease/increase in the area (sq. ft.) of irrigation increase/decrease in the rooftop area captured, if feasible; add to/subtract from an on-site infiltration facility; etc.).

RESULT TO BE TRANSFERRED TO RUNOFF REDUCTION SPREADSHEET

15. First Value to Transfer: Once the cistern storage volume associated with the TVC has been selected, simply transfer that credit amount into the Runoff Reduction Spreadsheet column called “Credit” in the “2.f. To Rain Barrel, Rainwater harvesting system, Cistern” row in the blue cell (cell F30).

16. Second Value to Transfer: Then enter the rooftop area that was used in the same row and in the Cistern Design Spreadsheet into the “Credit Area (acres)” column in the blue cell (cell G30).

APPENDIX 6-C

NOTES REGARDING THE CISTERN DESIGN SPREADSHEET USE AND METHODOLOGY

If a use is only seasonal (e.g. summer irrigation), the spreadsheet must set the input for irrigation to zero for the purpose of the Treatment Volume credit, unless an on-site infiltration facility is designed to infiltrate an equivalent volume of water during the non irrigation season.

With each documented daily use, the runoff volume is reduced. The Treatment Volume credit is a percentage equivalent to the sum of all the stored water that is used/disposed during the entire 30 year period divided by the entire volume that is generated during that same period for all storm events of 1-inch or less. That is:

$$Tv\% = \frac{\sum_{i=1}^{n} Vu}{\sum_{i=1}^{n} Tv}$$

Where:

$$\sum_{i=1}^{n} Tv = \sum_{i=1}^{n}\left[Pi \times SA \times Rv \times \left(\frac{1ft}{12in}\right) \times \left(\frac{7.48gallons}{1cf}\right)\right]$$

And

$$\sum_{i=1}^{n} Vu = \sum\left[Tv - ff - Ov\right]$$

Where: $Tv\%$ = Treatment Volume credit (%)

$\sum_{i=1}^{n} Vu$ = Runoff Reduction Volume.

(NOTE: This is the total volume of runoff that has been removed from the runoff for storms of 1 inch or less for the entire 30 year period. It is calculated adding the contribution all precipitation of 1 inch or less, times the runoff coefficient, minus the first flush diversion, minus the overflow.)

ff = First flush diversion and filter overflow due to filter inefficiency

Ov = Overflow from precipitation events of 1 inch or less

Rv = Runoff Coefficient of the Rooftop = 0.95

Pi = Precipitation of 1 inch or less (inches)

SA = Surface Area of the rooftop that is captured and conveyed to the cistern (sq. ft.)

i = Start day of modeling (First day modeled in 1977)

n = End day of modeling (Last day modeled in 2007)

The spreadsheet calculations should always be included with the stormwater management submittal package for local plan review. See Appendix 6-D for more information on recommended submittal package checklists and materials.

APPENDIX 6-D

PLAN SUBMITTAL REQUIREMENTS AND CHECKLIST RECOMMENDATIONS

It is highly recommended that designers of rainwater harvesting systems coordinate design efforts and communicate intent to both site designers and building architects, since a rainwater harvesting system links the building to the site. The effectiveness of such a system, in terms of use for demand and as a stormwater management tool, is also highly dependent on the efficiency of capturing and conveying rainwater from the building rooftop (or other impervious cover) to the storage tank.

The following lists are recommended items that plan reviewers may want to consider and/or require for submittals of rainwater harvesting systems being used as a stormwater management tool. To ensure effectiveness of design, the following items should be considered for inclusion with plan submittals:

A. Incorporation of Rainwater Harvesting System into Site Plan Grading and Storm Sewer Plan construction documents, as follows:

1. Include a roof plan of the building that will be used to capture rainwater, showing slope direction and roof material.

2. Display downspout leaders from the rooftops being used to capture rainwater.

3. Display the storm drain pipe layout (pipes between building downspouts and the tank) in plan view, specifying materials, diameters, slopes and lengths, to be included on typical grading and utilities or storm sewer plan sheets.

4. Include a detail or note specifying the minimum size, shape configuration and slope ~~to~~ of the gutter(s) that convey rainwater

B. Rainwater Harvesting System Construction Document sheet, to show the following:

1. The Cistern or Storage Unit material and dimensions in a scaleable detail (use a cut sheet detail from Manufacturer, if appropriate).

2. Include the specific Filter Performance specification and filter efficiency curves. Runoff estimates from the rooftop area captured for 1-inch storm should be estimated and compared to filter efficiencies for the 1-inch storm. It is assumed that the first flush diversion is included in filter efficiency curves. A minimum of 95% filter efficiency should be met for the Treatment Volume credit. If this value is altered (increased) in the Cistern Design Spreadsheet, the value should be reported. Filter curve cut sheets are normally available from the manufacturer.

3. Show the specified materials and diameters of inflow and outflow pipes.

4. Show the inverts of the orifice outlet, the emergency overflows, and, if applicable, the receiving secondary runoff reduction practice or on-site infiltration facility.

5. Show the incremental volumes specified for: (a) the low water cut-off volume level; (b) the storage volume associated with the Treatment Volume credit; (c) the storage volume associated with the Channel Protection Volume (if applicable); (d) the storage volume associated with the Flood Protection Volume (if applicable); and (e) the overflow freeboard volume.

6. Include a cross section of the storage unit displaying the inverts associated with the various incremental volumes (if requested by the reviewer).

C. Supporting Calculations and Documentation

1. Provide a drainage area map delineating the rooftop area (square feet) to be captured and indicating the 1-inch storm, 1 year storm and 10 year storm peak discharge values on the plan (11x17 is sufficient).

2. Provide calculations showing that the gutter, at its specified size and slope, will convey the design storm specified by regulatory authority.

3. Provide calculations showing that the roof drains, at their specified size, slope and material, will convey the design storm specified by regulatory authority.

4. Cistern Design Spreadsheet: a print-out of the “Input” tab, as modeled.

5. Cistern Design Spreadsheet: a print-out of the “Results - Treatment Volume Credit” tab, as modeled.

6. Cistern Design Spreadsheet: a printout of the “Results” tab, as modeled.

D. Stormwater Management Forms

1. The owner should treat a rainwater harvesting system as he/she would treat any other stormwater management facility. If a stormwater management maintenance agreement form is required by the jurisdiction, then the same form should be submitted for a rainwater harvesting system.

2. An Agreement Form or Note on the plans should be included to ensure that the minimum demand that was specified in the stormwater management plan submittal documents ~~are~~ is being met. Likewise, if the property (and rainwater harvesting system) is transferred to a different owner, the new owner must be held responsible to ensure the system will continue to archive ~~a~~ the specified year-round drawdown. If the year-round drawdown is not being met as specified, an alternative stormwater management plan may be required.

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 7

PERMEABLE PAVEMENT

VERSION 1.8
March 1, 2011

SECTION 1: DESCRIPTION

Permeable pavements are alternative paving surfaces that allow stormwater runoff to filter through voids in the pavement surface into an underlying stone reservoir, where it is temporarily stored and/or infiltrated. A variety of permeable pavement surfaces are available, including **pervious concrete**, **porous asphalt** and permeable **interlocking concrete pavers**. While the specific design may vary, all permeable pavements have a similar structure, consisting of a surface pavement layer, an underlying stone aggregate reservoir layer and a filter layer or fabric installed on the bottom (See **Figure 7.1** below).

The thickness of the reservoir layer is determined by both a structural and hydrologic design analysis. The reservoir layer serves to retain stormwater and also supports the design traffic loads for the pavement. In low-infiltration soils, some or all of the filtered runoff is collected in an underdrain and returned to the storm drain system. If infiltration rates in the native soils permit, permeable pavement can be designed without an underdrain, to enable full infiltration of runoff. A combination of these methods can be used to infiltrate a portion of the filtered runoff.

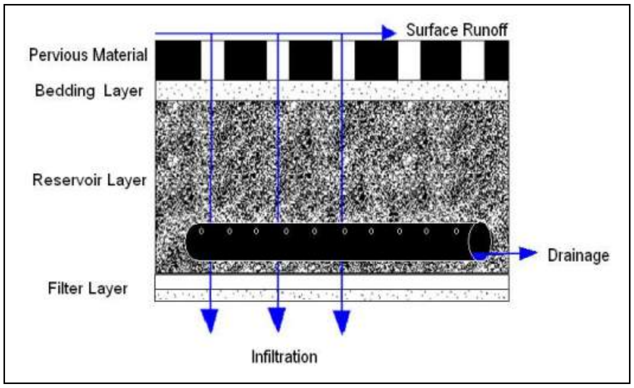


Figure 7.1. Cross Section of Typical Permeable Pavement (Source: Hunt & Collins, 2008)

Permeable pavement is typically designed to treat stormwater that falls on the actual pavement surface area, but it may also be used to accept run-on from small adjacent impervious areas, such as impermeable driving lanes or rooftops. However, careful sediment control is needed for any run-on areas to avoid clogging of the down-gradient permeable pavement. Permeable pavement has been used at commercial, institutional, and residential sites in spaces that are traditionally impervious. Permeable pavement promotes a high degree of runoff volume reduction and nutrient removal, and it can also reduce the effective impervious cover of a development site.

SECTION 2: PERFORMANCE

The overall stormwater functions of permeable pavement are shown in **Table 7.1**.

Table 7.1. Summary of Stormwater Functions Provided by Permeable Pavement

Stormwater Function	Level 1 Design	Level 2 Design
Annual Runoff Volume Reduction (RR)	45%	75%
Total Phosphorus (TP) EMC Reduction[1] by BMP Treatment Process	25%	25%
Total Phosphorus (TP) Mass Load Removal	59%	81%
Total Nitrogen (TN) EMC Reduction[1]	25%	25%
Total Nitrogen (TN) Mass Load Removal	59%	81%
Channel Protection	● Use RRM spreadsheet to calculate a Curve Number (CN) adjustment; ***OR*** ● Design extra storage (optional, as needed) in the stone underdrain layer to accommodate larger storm volumes, and use NRCS TR-55 Runoff Equations [2] to compute a CN adjustment.	
Flood Mitigation	Partial. May be able to design additional storage into the reservoir layer by adding perforated storage pipe or chambers.	
[1] Change in event mean concentration (EMC) through the practice. Actual nutrient mass load removed is the product of the removal rate and the runoff reduction rate (see Table 1 in the *Introduction to the New Virginia Stormwater Design Specifications*). [2] NRCS TR-55 Runoff Equations 2-1 thru 2-5 and Figure 2-1 can be used to compute a curve number adjustment for larger storm events based on the retention storage provided by the practice(s).		

Sources: CWP and CSN (2008) and CWP (2007)

The choice of what kind of permeable pavement to use is influenced by site-specific design factors and the intended future use of the permeable surface. A general comparison of the engineering properties of the three major permeable pavement types is provided in **Table 7.2**, although designers should check with product vendors and their local review authority to determine their specific requirements and capabilities. Designers should also note that there are other paver options, such as concrete grid pavers and reinforced turf pavers, that function in the same general manner as permeable pavement.

Table 7.2. Comparative Properties of the Three Major Permeable Pavement Types

Design Factor	Porous Concrete (PC)	Porous Asphalt (PA)	Interlocking Pavers (IP)
Scale of Application	Small and large scale paving applications	Small and large scale paving applications	Micro, small and large scale paving applications
Pavement Thickness [1]	5 to 8 inches	3 to 4 inches	3 inches [1, 8]
Bedding Layer [1, 8]	None	2 inches No. 57 stone	2 inches of No. 8 stone
Reservoir Layer [2, 8]	No. 57 stone	No. 2 stone	No. 2 stone 3-4 inches of No.57 stone
Construction Properties [3]	Cast in place, seven day cure, must be covered	Cast in place, 24 hour cure	No cure period; manual or mechanical installation of pre-manufactured units, over 5000 sf/day per machine
Design Permeability [4]	10 feet/day	6 feet/day	2 feet/day
Construction Cost [5]	$ 2.00 to $6.50/sq. ft.	$ 0.50 to $1.00/ sq. ft.	$ 5.00 to $ 10.00/ sq. ft.
Min. Batch Size	500 sq. ft.		NA
Longevity [6]	20 to 30 years	15 to 20 years	20 to 30 years
Overflow	Drop inlet or overflow edge	Drop inlet or overflow edge	Surface, drop inlet or overflow edge
Temperature Reduction	Cooling in the reservoir layer	Cooling in the reservoir layer	Cooling at the pavement surface & reservoir layer
Colors/Texture	Limited range of colors and textures	Black or dark grey color	Wide range of colors, textures, and patterns
Traffic Bearing Capacity [7]	Can handle all traffic loads, with appropriate bedding layer design.		
Surface Clogging	Replace paved areas or install drop inlet	Replace paved areas or install drop inlet	Replace permeable stone jointing materials
Other Issues		Avoid seal coating	Snowplow damage
Design Reference	American Concrete Institute # 522.1.08	Jackson (2007) NAPA	Smith (2006) ICPI

[1] Individual designs may depart from these typical cross-sections, due to site, traffic and design conditions.
[2] Reservoir storage may be augmented by corrugated metal pipes, plastic arch pipe, or plastic lattice blocks.
[3] ICPI (2008)
[4] NVRA (2008)
[5] WERF 2005 as updated by NVRA (2008)
[6] Based on pavement being maintained properly, Resurfacing or rehabilitation may be needed after the indicated period.
[7] Depends primarily on on-site geotechnical considerations and structural design computations.
[8] Stone sizes correspond to ASTM D 448: *Standard Classification for Sizes of Aggregate for Road and Bridge Construction*.

SECTION 3: DESIGN TABLE

The major design goal of Permeable Pavement is to maximize nutrient removal and runoff reduction. To this end, designers may choose to use a baseline permeable pavement design (Level 1) or an enhanced design (Level 2) that maximizes nutrient and runoff reduction. To qualify for Level 2, the design must meet all design criteria shown in the right hand column of **Table 7.3**.

Table 7.3. Permeable Pavement Design Criteria

Level 1 Design	Level 2 Design
Tv = (1)(Rv)(A) / 12 – the volume reduced by an upstream BMP [1]	Tv = (1.1)(Rv)(A) / 12
Soil infiltration is less than 0.5 in./hr.	Soil infiltration rate exceeds 0.5 in./hr.
Underdrain required	Underdrain not required; ***OR*** If an underdrain is used, a 12-inch stone sump must be provided below the underdrain invert; ***OR*** The Tv has at least a 48-hour drain time, as regulated by a control structure.
CDA = The permeable pavement area plus upgradient parking, as long as the ratio of external contributing area to permeable pavement does not exceed 2:1.	CDA = The permeable pavement area
[1] The contributing drainage area to the permeable pavements should be limited to paved surfaces, to avoid sediment wash-on, and sediment source controls and/or a pre-treatment strip or sump should be used. When pervious areas are conveyed to permeable pavement, pre-treatment must be provided, and the pre-treatment may qualify for a runoff reduction credit.	

SECTION 4: TYPICAL DETAILS

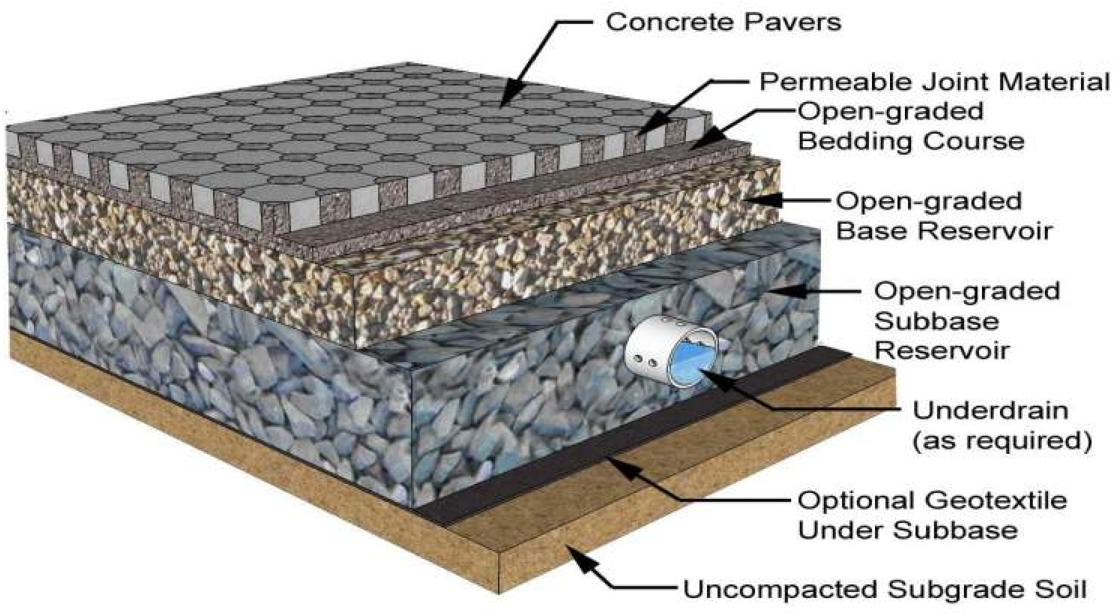


Figure 7.2. Typical Detail (Source: Smith, 2009)

SECTION 5: PHYSICAL FEASIBILITY & DESIGN APPLICATIONS

Since permeable pavement has a very high runoff reduction capability, it should always be considered as an alternative to conventional pavement. Permeable pavement is subject to the same feasibility constraints as most infiltration practices, as described below.

Available Space. A prime advantage of permeable pavement is that it does not normally require additional space at a new development or redevelopment site, which can be important for tight sites or areas where land prices are high.

Soils. Soil conditions do not constrain the use of permeable pavement, although they do determine whether an underdrain is needed. Impermeable soils in Hydrologic Soil Groups (HSG) C or D usually require an underdrain, whereas HSG A and B soils often do not. In addition, permeable pavement should never be situated above fill soils unless designed with an impermeable liner and underdrain.

If the proposed permeable pavement area is designed to infiltrate runoff without underdrains, it must have a minimum infiltration rate of 0.5 inches per hour. Initially, projected soil infiltration rates can be estimated from USDA-NRCS soil data, but they must be confirmed by an on-site infiltration measurement. Native soils must have silt/clay content less than 40% and clay content less than 20%.

> ***Designers should also evaluate existing soil properties during initial site layout, and seek to configure the site to conserve and protect the soils with the greatest recharge and infiltration rates. In particular, areas of HSG A or B soils shown on NRCS soil surveys should be considered as primary locations for all types of infiltration.***

External Drainage Area. Any external drainage area contributing runoff to permeable pavement should generally not exceed twice the surface area of the permeable pavement, and it should be as close to 100% impervious as possible. Some field experience has shown that an upgradient drainage area (even if it is impervious) can contribute particulates to the permeable pavement and lead to clogging (Hirschman, et al., 2009). Therefore, careful sediment source control and/or a pre-treatment strip or sump (e.g., stone or gravel) should be used to control sediment run-on to the permeable pavement section.

Pavement Slope. Steep slopes can reduce the stormwater storage capability of permeable pavement and may cause shifting of the pavement surface and base materials. Designers should consider using a terraced design for permeable pavement in sloped areas, especially when the local slope is several percent or greater.

The bottom slope of a permeable pavement installation should be as flat as possible (i.e., 0% longitudinal slope) to enable even distribution and infiltration of stormwater. However, a maximum longitudinal slope of 1% is permissible if an underdrain is employed. Lateral slopes should be 0%.

Minimum Hydraulic Head. The elevation difference needed for permeable pavement to function properly is generally nominal, although 2 to 4 feet of head may be needed to drive flows through underdrains. Flat terrain may affect proper drainage of Level 1 permeable pavement designs, so underdrains should have a minimum 0.5% slope.

Minimum Depth to Water Table. A high groundwater table may cause runoff to pond at the bottom of the permeable pavement system. Therefore, a minimum vertical distance of 2 feet must be provided between the bottom of the permeable pavement installation (i.e., the bottom invert of the reservoir layer) and the seasonal high water table.

Setbacks. Permeable pavement should not be hydraulically connected to structure foundations, in order to avoid harmful seepage. Setbacks to structures and roads vary, based on the scale of the permeable pavement installation (see **Table 7.3** above). At a minimum, small- and large-scale pavement applications should be located a minimum horizontal distance of 100 feet from any water supply well, 50 feet from septic systems, and at least 5 feet down-gradient from dry or wet utility lines. Setbacks can be reduced at the discretion of the local program authority for designs that use underdrains and/or liners.

Informed Owner. The property owner should clearly understand the unique maintenance responsibilities inherent with permeable pavement, particularly for parking lot applications. The owner should be capable of performing routine and long-term actions (e.g., vacuum sweeping) to maintain the pavement's hydrologic functions, and avoid future practices (e.g., winter sanding, seal coating or repaving) that diminish or eliminate them.

High Loading Situations. Permeable pavement is not intended to treat sites with high sediment or trash/debris loads, since such loads will cause the practice to clog and fail.

Groundwater Protection. **Section 10** of this specification presents a list of potential stormwater hotspots that pose a risk of groundwater contamination. Infiltration of runoff from designated hotspots is highly restricted or prohibited.

Limitations. Permeable pavement can be used as an alternative to most types of conventional pavement at residential, commercial and institutional developments, with two exceptions:

- Permeable pavement should not been used for high speed roads, although it has been successfully applied for low speed residential streets, parking lanes and roadway shoulders; and
- Permeable pavement should not be used to treat runoff from stormwater hotspots, as noted above. Refer to Section 10.1 of Stormwater Design Specification No. 8: (Infiltration) for more specific guidance regarding hotspots.

Design Scales. Permeable pavement can be installed at the following three scales:

1. The smallest scale is termed ***Micro-Scale Pavements***, which applies to converting impervious surfaces to permeable ones on small lots and redevelopment projects, where the installations may range from 250 to 1000 square feet in total area. Where redevelopment or

retrofitting of existing impervious areas results in a larger foot-print of permeable pavers (small-scale or large- scale, as described below), the designer should implement the Load Bearing, Observation Well, Underdrain, Soil Test, and Building Setback criteria associated with the applicable scale.

2. ***Small-scale pavement*** applications treat portions of a site between 1000 and 10,000 square feet in area, and include areas that only occasionally receive heavy vehicular traffic.

3. ***Large scale pavement*** applications exceed 10,000 square feet in area and typically are installed within portions of a parking lot.

Table 7.4 outlines the different design requirements for each of the three scales of permeable pavement installation.

Table 7.4. The Three Design Scales for Permeable Pavement

Design Factor	Micro-Scale Pavement	Small-Scale Pavement	Large-Scale Pavement
Impervious Area Treated	250 to 1000 sq. ft.	1000 to 10,000 sq. ft.	More than 10,000 sq. ft.
Typical Applications	Driveways Walkways Court Yards Plazas Individual Sidewalks	Sidewalk Network Fire Lanes Road Shoulders Spill-Over Parking Plazas	Parking Lots with more than 40 spaces Low Speed Residential Streets
Most Suitable Pavement	IP	PA, PC, and IP	PA, PC and IP
Load Bearing Capacity	Foot traffic Light vehicles	Light vehicles	Heavy vehicles (moving & parked)
Reservoir Size	Infiltrate or detain some or all of the Tv	Infiltrate or detain the full Tv and as much of the CPv and design storms as possible	
External Drainage Area?	No	Yes, impervious cover up to twice the permeable pavement area may be accepted as long as sediment source controls and/or pretreatment is used	
Observation Well	No	No	Yes
Underdrain?	Rare	Depends on the soils	Back-up underdrain
Required Soil Tests	One per practice	Two per practice	One per 5000 sq. ft of proposed practice
Building Setbacks	5 feet down-gradient 25 feet up-gradient	10 feet down-gradient 50 feet up-gradient	25 feet down-gradient 100 feet up-gradient

Regardless of the design scale of the permeable pavement installation, the designer should carefully consider the expected traffic load at the proposed site and the consequent structural requirements of the pavement system. Sites with heavy traffic loads will require a thick aggregate base and, in the case of porous asphalt and pervious concrete, may require the addition of an admixture for strength or a specific bedding design. In contrast, most micro-scale applications should have little or no traffic flow to contend with.

SECTION 6: DESIGN CRITERIA

6.1. Sizing of Permeable Pavement

Structural Design. If permeable pavement will be used in a parking lot or other setting that involves vehicles, the pavement surface must be able to support the maximum anticipated traffic load. The structural design process will vary according to the type of pavement selected, and the manufacturer's specific recommendations should be consulted. The thickness of the permeable pavement and reservoir layer must be sized to support structural loads and to temporarily store the design storm volume (e.g., the water quality, channel protection, and/or flood control volumes). On most new development and redevelopment sites, the structural support requirements will dictate the depth of the underlying stone reservoir.

The structural design of permeable pavements involves consideration of four main site elements:
- Total traffic;
- In-situ soil strength;
- Environmental elements; and
- Bedding and Reservoir layer design.

The resulting structural requirements may include, but are not limited to, the thickness of the pavement, filter, and reservoir layer. Designers should note that if the underlying soils have a low California Bearing Ratio (CBR) (less than 4%), they may need to be compacted to at least 95% of the Standard Proctor Density, which generally rules out their use for infiltration.

Designers should determine structural design requirements by consulting transportation design guidance sources, such as the following:

- VDOT Pavement Design Guide for Subdivision and Secondary Roads in Virginia (2000; or latest edition);
- AASHTO Guide for Design of Pavement Structures (1993); and,
- AASHTO Supplement to the Guide for Design of Pavement Structures (1998).

Hydraulic Design. Permeable pavement is typically sized to store the water quality Treatment Volume (T_v) or another design storm volume in the reservoir layer. The infiltration rate typically will be less than the flow rate through the pavement, so that some underground reservoir storage will usually be required. Designers should initially assume that there is no outflow through underdrains, using **Equation 7.1** to determine the depth of the reservoir layer, assuming runoff fully infiltrates into the underlying soil:

Equation 7.1

$$d_p = \frac{\{(d_c \times R) + P - (i/2 \times t_f)\ \}}{V_r}$$

Where:

d_p	= The depth of the reservoir layer (ft.)
d_c	= The depth of runoff from the contributing drainage area (not including the permeable paving surface) for the Treatment Volume (Tv/A_c), or other design storm (ft.)
R	= A_c/A_p = The ratio of the contributing drainage area (A_c, not including the permeable paving surface) to the permeable pavement surface area (A_p) [NOTE: With reference to **Table 7.3**, the maximum value for the Level 1 design is R = 2, (the external drainage area A_c is twice that of the permeable pavement area A_p; and for Level 2 design R = 0 (the drainage area is made up solely of permeable pavement A_p]**.**
P	= The rainfall depth for the Treatment Volume (Level 1 = 1 inch; Level 2 = 1.1 inch), or other design storm (ft.)
i	= The field-verified infiltration rate for native soils (ft./day)
t_f	= The time to fill the reservoir layer (day) – typically 2 hours or 0.083 day
V_r	= The void ratio for the reservoir layer (0.4)

The maximum allowable depth of the reservoir layer is constrained by the maximum allowable drain time, which is calculated using **Equation 2**.

Equation 7.2

$$d_{p-\max} = \frac{(i/2 \times t_d)}{V_r}$$

Where:

$d_{p\text{-}max}$	= The maximum depth of the reservoir layer (ft.)
i	= The field-verified infiltration rate for the native soils (ft./day)
V_r	= The void ratio for reservoir layer (0.4 – see assumptions, below)
t_d	= The maximum allowable time to drain the reservoir layer, typically 1 to 2 days (days)

The following design assumptions apply to **Equations 7.1 and 7.2**:

- The contributing drainage area (A_c) should not contain pervious areas.
- For design purposes, the native soil infiltration rate (i) should be the field-tested soil infiltration rate divided by a factor of safety of 2. The minimum acceptable native soil infiltration rate is 0.5”/hr.
- The void ratio (V_r) for No. 57 stone = 0.4.
- Max. drain time for the reservoir layer should be not less than 24 nor more than 48 hours.

If the depth of the reservoir layer is too great (i.e. d_p exceeds $d_{p\text{-max}}$), or the verified soil infiltration rate is less than 0.5 inches per hour, then the design method typically changes to account for underdrains. The storage volume in the pavements must account for the underlying infiltration rate and outflow through the underdrain. In this case, the design storm should be routed through the pavement to accurately determine the required reservoir depth. Alternatively, the designer may use **Equations 7.3 through 7.5** to approximate the depth of the reservoir layer for designs using underdrains.

Equation 7.3 can be used to approximate the outflow rate from the underdrain. The hydraulic conductivity, *k*, of gravel media is very high (~17,000 ft./day). However, the permeable pavement reservoir layer will drain increasingly slower as the storage volume decreases (i.e. the hydraulic head decreases). To account for this change, a conservative permeability coefficient of 100 ft./day can be used to approximate the average underdrain outflow rate.

Equation 7.3

$$q_u = k \times m$$

Where:

q_u = Outflow through the underdrain (per outlet pipe, assumed 6-inch diameter) (ft./day)
k = Hydraulic conductivity for the reservoir layer (ft./day – assume 100 ft./day)
m = Underdrain pipe slope (ft./ft.)

Once the outflow rate through the underdrain has been approximated, **Equation 7.4** is used to determine the depth of the reservoir layer needed to store the design storm.

Equation 7.4

$$d_p = \frac{\{(d_c \times R) + P - (i/2 \times t_f) - (q_u \times t_f)\}}{V_r}$$

Where:

d_p = Depth of the reservoir layer (ft.)
d_c = Depth of runoff from the contributing drainage area (not including the permeable pavment surface) for the Treatment Volume (Tv/A_c), or other design storm (ft.)
R = A_c/A_p = The ratio of the contributing drainage area (A_c) (not including the permeable pavment surface) to the permeable pavement surface area (A_p)
P = The rainfall depth for the Treatment Volume (Level 1 = 1 inch; Level 2 = 1.1 inch), or other design storm (ft.)
i = The field-verified infiltration rate for the native soils (ft./day)
t_f = The time to fill the reservoir layer (day) – typically 2 hours or 0.083 day
V_r = The void ratio for the reservoir layer (0.4)
q_u = Outflow through Underdrain (ft/day)

The maximum allowable depth of the reservoir layer is constrained by the maximum allowable drain time, which is calculated using **Equation 7.5**.

Equation 7.5

$$d_{p-\max} = \frac{\{(i/2 \times t_d) + (q_u \times t_d)\}}{V_r}$$

Where:

d_{p-max} = The maximum depth of the reservoir layer (ft.)
i = The field-verified infiltration rate for the native soils (ft./day)
V_r = The void ratio for the reservoir layer (0.4)
t_d = The time to drain the reservoir layer (day – typically 1 to 2 days)
q_u = The outflow through the underdrain (ft./day)

If the depth of the reservoir layer is still too great (i.e. d_p exceeds d_{p-max}), the number of underdrains can be increased, which will increase the underdrain outflow rate.

Permeable pavement can also be designed to address, in whole or in part, the detention storage needed to comply with channel protection and/or flood control requirements. The designer can model various approaches by factoring in storage within the stone aggregate layer, expected infiltration, and any outlet structures used as part of the design. Routing calculations can also be used to provide a more accurate solution of the peak discharge and required storage volume.

Once runoff passes through the surface of the permeable pavement system, designers should calculate outflow pathways to handle subsurface flows. Subsurface flows can be regulated using underdrains, the volume of storage in the reservoir layer, the bed slope of the reservoir layer, and/or a control structure at the outlet.

6.2. Soil Infiltration Rate Testing

To design a permeable pavement system *without* an underdrain, the measured infiltration rate of subsoils must be 0.5 inch per hour or greater. On-site soil infiltration rate testing procedures are outlined in Appendix 8-A of the Infiltration Design Specification (No. 8). A minimum of one test must be taken per 1,000 sq. ft. of planned permeable pavement surface area. In most cases, a single soil test is sufficient for micro-scale and small-scale applications. At least one soil boring must be taken to confirm the underlying soil properties *at the depth where infiltration is designed to occur* (i.e., to ensure that the depth to water table, depth to bedrock, or karst is defined). Soil infiltration testing should be conducted within any confining layers that are found within 4 feet of the bottom of a proposed permeable pavement system.

6.3. Type of Surface Pavement

The type of pavement should be selected based on a review of the factors in **Table 7.2** above, and designed according to the product manufacturer's recommendations.

6.4. Internal Geometry and Drawdowns

- ***Elevated Underdrain.*** To promote greater runoff reduction for permeable pavement located on marginal soils, an elevated underdrain should be installed with a stone jacket that creates a 12 to 18 inch deep storage layer *below* the underdrain invert. The void storage in this layer can help qualify a site to achieve Level 2 design.

- ***Rapid Drawdown.*** When possible, permeable pavement should be designed so that the target runoff reduction volume stays in the reservoir layer for at least 36 hours before being discharged through an underdrain.

- ***Conservative Infiltration Rates.*** Designers should always decrease the measured infiltration rate by a factor of 2 during design, to approximate long term infiltration rates.

6.5. Pretreatment

Pretreatment for most permeable pavement applications is not necessary, since the surface acts as pretreatment to the reservoir layer below. Additional pretreatment may be appropriate if the pavement receives run-on from an adjacent pervious or impervious area. For example, a gravel filter strip can be used to trap coarse sediment particles before they reach the permeable pavement surface, in order to prevent premature clogging.

6.6. Conveyance and Overflow

Permeable pavement designs should include methods to convey larger storms (e.g., 2-yr, 10-yr) to the storm drain system. The following is a list of methods that can be used to accomplish this:

- Place a perforated pipe horizontally near the top of the reservoir layer to pass excess flows after water has filled the base. The placement and/or design should be such that the incoming runoff is not captured (e.g., placing the perforations on the underside only).
- Increase the thickness of the top of the reservoir layer by as much as 6 inches (i.e., create freeboard). The design computations used to size the reservoir layer often assume that no freeboard is present.
- Create underground detention within the reservoir layer of the permeable pavement system. Reservoir storage may be augmented by corrugated metal pipes, plastic or concrete arch structures, etc.
- Route excess flows to another detention or conveyance system that is designed for the management of extreme event flows.
- Set the storm drain inlets flush with the elevation of the permeable pavement surface to effectively convey excess stormwater runoff past the system (typically in remote areas). The design should also make allowances for relief of unacceptable ponding depths during larger rainfall events.

6.7. Reservoir layer

The thickness of the reservoir layer is determined by runoff storage needs, the infiltration rate of in situ soils, structural requirements of the pavement sub-base, depth to water table and bedrock, and frost depth conditions (see **Section 7**). A professional should be consulted regarding the suitability of the soil subgrade.

- The reservoir below the permeable pavement surface should be composed of clean, washed stone aggregate and sized for both the storm event to be treated and the structural requirements of the expected traffic loading.
- The storage layer may consist of clean washed No. 57 stone, although No. 2 stone is preferred because it provides additional storage and structural stability.
- The bottom of the reservoir layer should be completely flat so that runoff will be able to infiltrate evenly through the entire surface.

6.8 Underdrains

The use of underdrains is recommended when there is a reasonable potential for infiltration rates to decrease over time, when underlying soils have an infiltration rate of less than 1/2-inch per hour, or when soils must be compacted to achieve a desired Proctor density. Underdrains can also be used to manage extreme storm events to keep detained stormwater from backing up into the permeable pavement.

- An underdrain(s) should be placed within the reservoir and encased in 8 to 12 inches of clean, washed stone.
- The underdrain outlet can be fitted with a flow-reduction orifice as a means of regulating the stormwater detention time. The minimum diameter of any orifice should be 0.5 inch.
- An underdrain(s) can also be installed and capped at a downstream structure as an option for future use if maintenance observations indicate a reduction in the soil permeability.

6.9. Maintenance Reduction Features

Maintenance is a crucial element to ensure the long-term performance of permeable pavement. The most frequently cited maintenance problem is surface clogging caused by organic matter and sediment, which can be reduced by the following measures:

- ***Periodic Vacuum Sweeping.*** The pavement surface is the first line of defense in trapping and eliminating sediment that may otherwise enter the stone base and soil subgrade. The rate of sediment deposition should be monitored and vacuum sweeping done once or twice a year. This frequency should be adjusted according to the intensity of use and deposition rate on the permeable pavement surface. At least one sweeping pass should occur at the end of winter.

- ***Protecting the Bottom of the Reservoir Layer.*** There are two options to protect the bottom of the reservoir layer from intrusion by underlying soils. The first method involves covering the bottom with nonwoven, polypropylene geotextile that is permeable, although some practitioners recommend avoiding the use of filter fabric since it may become a future plane of clogging within the system. Permeable filter fabric is still recommended to protect the excavated sides of the reservoir layer, in order to prevent soil piping. The second method is to form a barrier of choker stone and sand. In this case, underlying native soils should be separated from the reservoir base/subgrade layer by a thin 2 to 4 inch layer of clean, washed, choker stone (ASTM D 448 No. 8 stone) covered by a layer of 6 to 8 inches of course sand.

- ***Observation Well.*** An observation well, consisting of a well-anchored, perforated 4 to 6 inch (diameter) PVC pipe that extends vertically to the bottom of the reservoir layer, should be installed at the downstream end of all large-scale permeable pavement systems. The observation well should be fitted with a lockable cap installed flush with the ground surface (or under the pavers) to facilitate periodic inspection and maintenance. The observation well is used to observe the rate of drawdown within the reservoir layer following a storm event.

- ***Overhead Landscaping.*** Most local communities now require from 5% to 10% (or more) of the area of parking lots to be in landscaping. Large-scale permeable pavment applications should be carefully planned to integrate this landscaping in a manner that maximizes runoff treatment and minimizes the risk that sediment, mulch, grass clippings, leaves, nuts, and fruits will inadvertently clog the paving surface.

6.10. Material Specifications

Permeable pavement material specifications vary according to the specific pavement product selected. **Table 7.5** describes general material specifications for the component structures installed beneath the permeable pavement. Note that the size of stone materials used in the reservoir and filter layers may differ depending whether the system is PC, PA or IP (see **Table 7.2** above). A general comparison of different permeable pavements is provided in **Table 7.6** below, but designers should consult manufacturer's technical specifications for specific criteria and guidance.

Table 7.5. Material Specifications for Underneath the Pavement Surface

Material	Specification	Notes
Bedding Layer	PC: None PA: 2 in. depth of No. 8 stone IP: 2 in. depth of No. 8 stone over 3 to 4 inches of No. 57	ASTM D448 size No. 8 stone (e.g. 3/8 to 3/16 inch in size). Should be double-washed and clean and free of all fines.
Reservoir Layer	PC: No. 57 stone PA: No. 2 stone IP: No. 57 stone	ASTM D448 size No. 57 stone (e.g. 1 1/2 to 1/2 inch in size); No. 2 Stone (e.g. 3 inch to 3/4 inch in size). Depth is based on the pavement structural and hydraulic requirements. Should be double-washed and clean and free of all fines.
Underdrain	Use 4 to 6 inch diameter perforated PVC (AASHTO M 252) pipe, with 3/8-inch perforations at 6 inches on center; each underdrain installed at a minimum 0.5% slope located 20 feet or less from the next pipe (or equivalent corrugated HDPE may be used for smaller load-bearing applications). Perforated pipe installed for the full length of the permeable pavement cell, and non-perforated pipe, as needed, is used to connect with the storm drain system. T's and Y's installed as needed, depending on the underdrain configuration. Extend cleanout pipes to the surface with vented caps at the Ts and Ys.	
Filter Layer	The underlying native soils should be separated from the stone reservoir by a thin, 2 to 4 inch layer of choker stone (e.g. No. 8) covered by a 6 to 8 inch layer of coarse sand (e.g. ASTM C 33, 0.02-0.04 inch).	The sand should be placed between the stone reservoir and the choker stone, which should be placed on top of the underlying native soils.
Filter Fabric (optional)	Use a needled, non-woven, polypropylene geotextile with Grab Tensile Strength equal to or greater than 120 lbs (ASTM D4632), with a Mullen Burst Strength equal to or greater than 225 lbs./sq. in. (ASTM D3786), with a Flow Rate greater than 125 gpm/sq. ft. (ASTM D4491), and an Apparent Opening Size (AOS) equivalent to a US # 70 or # 80 sieve (ASTM D4751). The geotextile AOS selection is based on the percent passing the No. 200 sieve in "A" Soil subgrade, using FHWA or AASHTO selection criteria.	
Impermeable Liner	Use a thirty mil (minimum) PVC Geomembrane liner covered by 8 to 12 oz./sq. yd.~~2~~ non-woven geotextile. NOTE: THIS IS USED ONLY FOR KARST REGIONS.	
Observation Well	Use a perforated 4 to 6 inch vertical PVC pipe (AASHTO M 252) with a lockable cap, installed flush with the surface.	

Table 7.6. Different Permeable Pavement Specifications

Material	Specification	Notes
Permeable Interlocking Concrete Pavers	Surface open area: 5% to 15%. Thickness: 3.125 inches for vehicles. Compressive strength: 55 Mpa. Open void fill media: aggregate	Must conform to ASTM C936 specifications. Reservoir layer required to support the structural load.
Concrete Grid Pavers	Open void content: 20% to 50%. Thickness: 3.5 inches. Compressive strength: 35 Mpa. Open void fill media: aggregate, topsoil and grass, coarse sand.	Must conform to ASTM C 1319 specifications. Reservoir layer required to support the structural load.
Plastic Reinforced Grid Pavers	Void content: depends on fill material. Compressive strength: varies, depending on fill material. Open void fill media: aggregate, topsoil and grass, coarse sand.	Reservoir layer required to support the structural load.
Pervious Concrete	Void content: 15% to 25 %. Thickness: typically 4 to 8 inches. Compressive strength: 2.8 to 28 Mpa. Open void fill media: None	May not require a reservoir layer to support the structural load, but a layer may be included to increase the storage or infiltration.
Porous Asphalt	Void content: 15% to 20 %. Thickness: typically 3 to 7 in. (depending on traffic load). Open void fill media: None.	Reservoir layer required to support the structural load.

SECTION 7: REGIONAL & SPECIAL CASE DESIGN ADAPTATIONS

The design adaptations described below permit permeable pavement to be used on a wider range of sites. However, it is important not to force this practice onto marginal sites. Other runoff reduction practices are often preferred alternatives for difficult sites.

7.1. Karst Terrain

Karst terrain is found in much of the Ridge and Valley physiographic regions of Virginia. Karst complicates both land development and stormwater design. A detailed geotechnical investigation may be required for any kind of stormwater design in karst terrain (see CSN Technical Bulletin No. 1; and the Virginia SWM Handbook).

- The use of Level 2 (i.e. infiltration) permeable pavement designs at sites with known karst features may cause the formation of sinkholes (especially for large scale pavement applications) and are, therefore, not recommended. Designers should also avoid a Level 2 permeable pavement design if the site is designated as a severe stormwater hotspot, or will discharge to areas known to provide groundwater recharge to an aquifers that is used as a water supply source.
- Micro-scale and small-scale permeable pavement installations are acceptable if they are designed according to the Level 1 criteria (i.e., they possess an impermeable bottom liner and an underdrain).
- The stone used in the reservoir layer should be carbonate in nature to provide extra chemical buffering capacity.

7.2. Coastal Plain

Experience in North Carolina has shown that properly designed and installed permeable pavement systems can work effectively in the demanding conditions of the coastal plain, if the following conditions are met:

- Designers should ensure that the distance from the bottom of the permeable pavement system to the top of the water table is at least 2 feet.
- If an underdrain is used beneath permeable pavement, a minimum 0.5% slope must be maintained to ensure proper drainage.

7.3. Piedmont/Clay Soils

In areas where the underlying soils are not suitable for complete infiltration, permeable pavement systems with underdrains can still function effectively to reduce runoff volume and nutrient loads.

- If the underlying soils have an infiltration rate of less than 0.5 in./hr., an underdrain must be installed to ensure proper drainage from the system.
- Permeable pavement should not be installed over underlying soils with a high shrink/swell potential.

- To promote greater runoff reduction for permeable pavement located on marginal soils, an elevated underdrain configuration may be used (see **Section 8.3**).

7.4. Cold Climate and Winter Performance

In cold climates and winter conditions, freeze-thaw cycles may affect the structural durability of the permeable pavement system. In these situations, the following design adaptations may be helpful:

- To avoid damage caused by freezing, designs should not allow water to pond in or above the permeable pavement. Ensure complete drainage of the permeable pavement system within 24 hours following a rainfall event.
- Extend the filter bed and underdrain pipe below the frost line and/or oversize the underdrain by one pipe size, to reduce the freezing potential.
- Large snow storage piles should be located in adjacent grassy areas so that sediments and pollutants in snowmelt are partially treated before they reach the permeable pavement.
- Sand should never be applied for winter traction over permeable pavement or areas of standard (impervious) pavement that drain toward permeable pavement, since it will quickly clog the system.
- When plowing plastic reinforced grid pavements, snow plow blades should be lifted 1/2 inch to 1 inch above the pavement surface to prevent damage to the paving blocks or turf. Porous asphalt (PA), pervious concrete (PC) and interlocking pavers (IP) can be plowed similar to traditional pavements, using similar equipment and settings.
- Owners should be judicious when using chloride products for deicing over all permeable pavements designed for infiltration, since the salts will most assuredly be transmitted into the groundwater.

SECTION 8: CONSTRUCTION

Experience has shown that proper installation is absolutely critical to the effective operation of a permeable pavement system.

8.1 Necessary Erosion & Sediment Controls

- All permeable pavement areas should be fully protected from sediment intrusion by silt fence or construction fencing, particularly if they are intended to infiltrate runoff.
- Permeable pavement areas should remain outside the limit of disturbance during construction to prevent soil compaction by heavy equipment. Permeable pavement areas should be clearly marked on all construction documents and grading plans. To prevent soil compaction, heavy vehicular and foot traffic should be kept out of permeable pavement areas during and immediately after construction.
- During construction, care should be taken to avoid tracking sediments onto any permeable pavement surface to avoid clogging.
- Any area of the site intended ultimately to be a permeable pavement area should generally not be used as the site of a temporary sediment basin. Where locating a sediment basin on an area intended for permeable pavement is unavoidable, the invert of the sediment basin must

be a minimum of 2 feet above the final design elevation of the bottom of the aggregate reservoir course. All sediment deposits in the excavated area should be carefully removed prior to installing the subbase, base and surface materials.

8.2. Permeable Pavement Construction Sequence

The following is a typical construction sequence to properly install permeable pavement, which may need to be modified to depending on whether Porous Asphalt (PA), Pervious Concrete (PC) or Interlocking Paver (IP) designs are employed.

Step 1. Construction of the permeable pavement shall only begin after the entire contributing drainage area has been stabilized. The proposed site should be checked for existing utilities prior to any excavation. Do not install the system in rain or snow, and do not install frozen bedding materials.

Step 2. As noted above, temporary erosion and sediment (E&S) controls are needed during installation to divert stormwater away from the permeable pavement area until it is completed. Special protection measures such as erosion control fabrics may be needed to protect vulnerable side slopes from erosion during the excavation process. The proposed permeable pavement area must be kept free from sediment during the entire construction process. Construction materials that are contaminated by sediments must be removed and replaced with clean materials.

Step 3. Where possible, excavators or backhoes should work from the sides to excavate the reservoir layer to its appropriate design depth and dimensions. For micro-scale and small-scale pavement applications, excavating equipment should have arms with adequate extension so they do not have to work inside the footprint of the permeable pavement area (to avoid compaction). Contractors can utilize a cell construction approach, whereby the proposed permeable pavement area is split into 500 to 1000 sq. ft. temporary cells with a 10 to 15 foot earth bridge in between, so that cells can be excavated from the side. Excavated material should be placed away from the open excavation so as to not jeopardize the stability of the side walls.

Step 4. The native soils along the bottom and sides of the permeable pavement system should be scarified or tilled to a depth of 3 to 4 inches prior to the placement of the filter layer or filter fabric. In large scale paving applications with weak soils, the soil subgrade may need to be compacted to 95% of the Standard Proctor Density to achieve the desired load-bearing capacity. (NOTE: This effectively eliminates the infiltration function of the installation, and it must be addressed during hydrologic design.)

Step 5. Filter fabric should be installed on the bottom and the sides of the reservoir layer. In some cases, an alternative filter layer, as described in **Section 8.6** may be warranted. Filter fabric strips should overlap down-slope by a minimum of 2 feet, and be secured a minimum of 4 feet beyond the edge of the excavation. Where the filter layer extends beyond the edge of the pavement (to convey runoff to the reservoir layer), install an additional layer of filter fabric 1 foot below the surface to prevent sediments from entering into the reservoir layer. Excess filter fabric should not be trimmed until the site is fully stabilized.

Step 6. Provide a minimum of 2 inches of aggregate above and below the underdrains. The underdrains should slope down towards the outlet at a grade of 0.5% or steeper. The up-gradient end of underdrains in the reservoir layer should be capped. Where an underdrain pipe is connected to a structure, there shall be no perforations within 1 foot of the structure. Ensure that there are no perforations in clean-outs and observation wells within 1 foot of the surface.

Step 7. Moisten and spread 6-inch lifts of the appropriate clean, washed stone aggregate (usually No. 2 or No. 57 stone). Place at least 4 inches of additional aggregate above the underdrain, and then compact it using a vibratory roller in static mode until there is no visible movement of the aggregate. Do not crush the aggregate with the roller.

Step 8. Install the desired depth of the bedding layer, depending on the type of pavement, as follows:

- **Pervious Concrete:** No bedding layer is used.
- **Porous Asphalt:** The bedding layer for porous asphalt pavement consists of 1 to 2 inches of clean, washed ASTM D 448 No.57 stone. The filter course must be leveled and pressed (choked) into the reservoir base with at least four (4) passes of a 10-ton steel drum static roller.
- **Interlocking Pavers:** The bedding layer for open-jointed pavement blocks should consist of 1-1/2 to 2 inches of washed ASTM D 448 No.8 stone. The thickness of the bedding layer is to be based on the block manufacturer's recommendation or that of a qualified professional.

Step 9. Paving materials shall be installed in accordance with manufacturer or industry specifications for the particular type of pavement.

- **Installation of Porous Asphalt.** The following has been excerpted from various documents, most notably Jackson (2007).
  - Install porous asphalt pavement similarly to regular asphalt pavement. The pavement should be laid in a single lift over the filter course. The laying temperature should be between 230^{o}F and 260^{o}F, with a minimum air temperature of 50^{o}F, to ensure that the surface does not stiffen before compaction.
  - Complete compaction of the surface course when the surface is cool enough to resist a 10-ton roller. One or two passes of the roller are required for proper compaction. More rolling could cause a reduction in the porosity of the pavement.
  - The mixing plant must provide certification of the aggregate mix, abrasion loss factor, and asphalt content in the mix. Test the asphalt mix for its resistance to stripping by water using ASTM 1664. If the estimated coating area is not above 95%, additional anti-stripping agents must be added to the mix.
  - Transport the mix to the site in a clean vehicle with smooth dump beds sprayed with a non-petroleum release agent. The mix shall be covered during transportation to control cooling.
  - Test the full permeability of the pavement surface by application of clean water at a rate of at least five gallons per minute over the entire surface. All water must infiltrate directly, without puddle formation or surface runoff.

- Inspect the facility 18 to 30 hours after a significant rainfall (greater than 1/2 inch) or artificial flooding, to determine that the facility is draining properly.

- **Installation of Pervious Concrete.** The basic installation sequence for pervious concrete is outlined by the American Concrete Institute (2008). It is strongly recommended that concrete installers successfully complete a recognized pervious concrete installers training program, such as the Pervious Concrete Contractor Certification Program offered by the NRMCA. The basic installation procedure is as follows:
  - Drive the concrete truck as close to the project site as possible.
  - Water the underlying aggregate (reservoir layer) before the concrete is placed, so that the aggregate does not draw moisture from the freshly laid pervious concrete.
  - After the concrete is placed, approximately 3/8 to 1/2 inch is struck off, using a vibratory screed. This is to allow for compaction of the concrete pavement.
  - Compact the pavement with a steel pipe roller. Care should be taken so that over-compaction does not occur.
  - Cut joints for the concrete to a depth of 1/4 inch.
  - The curing process is very important for pervious concrete. Cover the pavement with plastic sheeting within 20 minutes of the strike-off, and keep it covered for at least seven (7) days. Do not allow traffic on the pavement during this time period.

- **Installation of Interlocking Pavers.** The basic installation process is described in greater detail by Smith (2006).
  - Place edge restraints for open-jointed pavement blocks before the bedding layer and pavement blocks are installed. Permeable interlocking concrete pavement (IP) systems require edge restraints to prevent vehicle loads from moving the paver blocks. Edge restraints may be standard VDOT curbs or gutter pans, or precast or cast-in-place reinforced concrete borders a minimum of 6 inches wide and 18 inches deep, constructed with Class A3 concrete. Edge restraints along the traffic side of a permeable pavement block system are recommended.
  - Place the No. 57 stone in a single lift. Level the filter course and compact it into the reservoir course beneath with at least four (4) passes of a 10-ton steel drum static roller until there is no visible movement. The first two (2) passes are in vibratory mode, with the final two (2) passes in static mode. The filter aggregate should be moist to facilitate movement into the reservoir course.
  - Place and screed the bedding course material (typically No. 8 stone).
  - Fill gaps at the edge of the paved areas with cut pavers or edge units. When cut pavers are needed, cut the pavers with a paver splitter or masonry saw. Cut pavers no smaller than one-third (1/3) of the full unit size.
  - Pavers may be placed by hand or with mechanical installers. Fill the joints and openings with stone. Joint openings must be filled with VDOT No. 8 stone, although VDOT No. 8P or No. 9 stone may be used where needed to fill narrower joints. Remove excess stones from the paver surface.
  - Compact and seat the pavers into the bedding course with a minimum low-amplitude 5,000-lbf, 75- to 95-Hz plate compactor.
  - Do not compact within 6 feet of the unrestrained edges of the pavers.

- The system must be thoroughly swept by a mechanical sweeper or vacuumed immediately after construction to remove any sediment or excess aggregate.
- Inspect the area for settlement. Any blocks that settle must be reset and re-inspected.
- Inspect the facility 18 to 30 hours after a significant rainfall (1/2 inch or greater) or artificial flooding to determine whether the facility is draining properly.

8.3. Construction Inspection

Inspections before, during and after construction are needed to ensure that permeable pavement is built in accordance with these specifications. Use detailed inspection checklists that require sign-offs by qualified individuals at critical stages of construction, to ensure that the contractor's interpretation of the plan is consistent with the designer's intent.

Some common pitfalls can be avoided by careful construction supervision that focuses on the following key aspects of permeable pavement installation:

- Store materials in a protected area to keep them free from mud, dirt, and other foreign materials.
- The contributing drainage area should be stabilized prior to directing water to the permeable pavement area.
- Check the aggregate material to confirm that it is clean and washed, meets specifications and is installed to the correct depth.
- Check elevations (e.g., the invert of the underdrain, inverts for the inflow and outflow points, etc.) and the surface slope.
- Make sure the permeable pavement surface is even, runoff evenly spreads across it, and the storage bed drains within 48 hours.
- Ensure that caps are placed on the upstream (but not the downstream) ends of the underdrains.
- Inspect the pretreatment structures (if applicable) to make sure they are properly installed and working effectively.
- Once the final construction inspection has been completed, log the GPS coordinates for each facility and submit them for entry into the local BMP maintenance tracking database.

It may be advisable to divert the runoff from the first few runoff-producing storms away from larger permeable pavement applications, particularly when up-gradient conventional asphalt areas drain to the permeable pavement. This can help reduce the input of fine particles that are often produced shortly after conventional asphalt is laid down.

SECTION 9: MAINTENANCE

9.1. Maintenance Agreements

Section 4 VAC 50-60-124 of the regulations specifies the circumstances under which a maintenance agreement must be executed between the owner and the local program. This section sets forth inspection requirements, compliance procedures if maintenance is neglected, notification of the local program upon transfer of ownership, and right-of-entry for local program personnel.

In addition, the maintenance agreements should also note which conventional parking lot maintenance tasks must be *avoided* (e.g., sanding, re-sealing, re-surfacing, power-washing). Signs should be posted on larger parking lots to indicate their stormwater function and special maintenance requirements.

When micro-scale or small-scale permeable pavement are installed on private residential lots, homeowners will need to (1) be educated about their routine maintenance needs, (2) understand the long-term maintenance plan, and (3) be subject to a deed restriction, drainage easement or other mechanism enforceable by the qualifying local program to help ensure that the permeable pavement system is maintained and functioning. The mechanism should, if possible, grant authority for local agencies to access the property for inspection or corrective action.

9.2. Maintenance Tasks

It is difficult to prescribe the specific types or frequency of maintenance tasks that are needed to maintain the hydrologic function of permeable pavement systems over time. Most installations work reasonably well year after year with little or no maintenance, whereas some have problems right from the start.

One preventative maintenance task for large-scale applications involves vacuum sweeping on a frequency consistent with the use and loadings encountered in the parking lot. Many consider an annual, dry-weather sweeping in the spring months to be important. The contract for sweeping should specify that a vacuum sweeper be used that does not use water spray, since spraying may lead to subsurface clogging. Vacuum settings for large-scale interlocking paver applications should be calibrated so they *do not* pick up the stones between pavement blocks.

9.3. Maintenance Inspections

It is highly recommended that a spring maintenance inspection and cleanup be conducted at each permeable pavement site, particularly at large-scale applications.

Maintenance of permeable pavement is driven by annual inspections that evaluate the condition and performance of the practice. The following are suggested annual maintenance inspection points for permeable pavements:

- The drawdown rate should be measured at the observation well for three (3) days following a storm event in excess of 1/2 inch in depth. If standing water is still observed in the well after three days, this is a clear sign that clogging is a problem.
- Inspect the surface of the permeable pavement for evidence of sediment deposition, organic debris, staining or ponding that may indicate surface clogging. If any signs of clogging are noted, schedule a vacuum sweeper (no brooms or water spray) to remove deposited material. Then, test sections by pouring water from a five gallon bucket to ensure they work.

- Inspect the structural integrity of the pavement surface, looking for signs of surface deterioration, such as slumping, cracking, spalling or broken pavers. Replace or repair affected areas, as necessary.
- Check inlets, pretreatment cells and any flow diversion structures for sediment buildup and structural damage. Note if any sediment needs to be removed.
- Inspect the condition of the observation well and make sure it is still capped.
- Generally inspect any contributing drainage area for any controllable sources of sediment or erosion.

An example maintenance inspection checklist for Permeable Pavement can be accessed in Appendix C of Chapter 9 of the *Virginia Stormwater Management Handbook* (2010). Based on inspection results, specific maintenance tasks will be triggered and scheduled to keep the facility in operating condition.

SECTION 10: COMMUNITY & ENVIRONMENTAL CONCERNS

Compliance with the Americans with Disabilities Act (ADA). Porous concrete and porous asphalt are generally considered to be ADA compliant. Most localities also consider interlocking concrete pavers to be complaint, if designers ensure that surface openings between pavers do not exceed 1/2 inch. However, some forms of interlocking pavers may not be suitable for handicapped parking spaces. Interlocking concrete pavers interspersed with other hardscape features (e.g., concrete walkways) *can* be used in creative designs to address ADA issues.

Groundwater Protection. While well-drained soils enhance the ability of permeable pavement to reduce stormwater runoff volumes, they may also increase the risk that stormwater pollutants might migrate into groundwater aquifers. Designers should avoid the use of infiltration-based permeable pavement in areas known to provide groundwater recharge to aquifers used for water supply. In these source water protection areas, designers should include liners and underdrains in large-scale permeable pavement applications (i.e., when the proposed surface area exceeds 10,000 square feet).

Stormwater Hotspots. Designers should also certify that the proposed permeable pavement area will not accept any runoff from a severe stormwater hotspot. Stormwater hotspots are operations or activities that are known to produce higher concentrations of stormwater pollutants and/or have a greater risk of spills, leaks or illicit discharges. Examples include certain industrial activities, gas stations, public works areas, petroleum storage areas (for a complete list of hotspots where infiltration is restricted or prohibited, see Stormwater Design Specification No. 8: Infiltration). For potential hotspots, restricted infiltration means that a minimum of 50% of the total T_v must be treated by a filtering or bioretention practice prior to the permeable pavement system. For known severe hotspots, the risk of groundwater contamination from spills, leaks or discharges is so great that infiltration of stormwater or snowmelt through permeable pavement is *prohibited*.

Underground Injection Control Permits. The Safe Drinking Water Act regulates the infiltration of stormwater in certain situations pursuant to the Underground Injection Control (UIC) Program, which is administered either by the EPA or a delegated state groundwater protection agency. In general, the EPA (2008) has determined that permeable pavement installations are not classified as Class V injection wells, since they are always wider than they are deep. There may be an exception in karst terrain if the discharge from permeable pavement is directed to an improved sinkhole, although this would be uncommon. More guidance on stormwater design in karst terrain can be found in CSN Technical Bulletin No. 1 (2008), and Appendix 6-C of Chapter 6 of the Virginia Stormwater Management Handbook (2010).

Cold Climate or Winter Time Operation. Experience has shown that permeable pavement can operate properly in snow and ice conditions, and there is evidence that a permeable surface increases meltwater rates compared to conventional pavement (thereby reducing the need for deicing chemicals). However, in larger parking lot applications certain snow management practices need to be modified to maintain the hydrologic function of the permeable pavement. These include not applying sand for traction and educating snowplow operators to keep blades from damaging the pavement surface. The jointing material for interlocking concrete paver systems (typically No. 8 stone) can be spread over surface ice to increase tire traction.

Air and Runoff Temperature. Permeable pavement appears to have some value in reducing summer runoff temperatures, which can be important in watersheds with sensitive cold-water fish populations. The temperature reduction effect is greatest when runoff is infiltrated into the sub-base, but some cooling may also occur in the reservoir layer, when underdrains are used. ICPI (2008) notes that the use of certain reflective colors for interlocking concrete pavers can also help moderate surface parking lot temperatures.

Vehicle Safety. Permeable pavement is generally considered to be a safer surface than conventional pavement, according to research reported by Smith (2006), Jackson (2007) and ACI (2008). Permeable pavement has less risk of hydroplaning, more rapid ice melt and better traction than conventional pavement.

SECTION 11: REFERENCES

American Society for Testing and Materials (ASTM). 2003. "Standard Classification for Sizes of Aggregate for Road and Bridge Construction." *ASTM D448-03a.* West Conshohocken, PA.

Chesapeake Stormwater Network (CSN). 2009. Technical Bulletin No. 1. *Stormwater Design Guidelines for Karst Terrain in the Chesapeake Bay watershed. Version 2.0*. Baltimore, MD. www.chesapeakestormwater.net

Hathaway, J. and W. Hunt. 2007. *Stormwater BMP Costs*. Report to NC DEHNR. Department of Biological and Agricultural Engineering. North Carolina State University. Raleigh, NC.

Hirschman, D., L. Woodworth and S. Drescher. 2009. *Technical Report: Stormwater BMPs in Virginia's James River Basin: An Assessment of Field Conditions & Programs*. Center for Watershed Protection. Ellicott City, MD.

Hunt, W. and K. Collins. 2008. "Permeable Pavement: Research Update and Design Implications." *North Carolina Cooperative Extension Service Bulletin.* Urban Waterways Series.

AG-588-14. North Carolina State University. Raleigh, NC. Available online at: http://www.bae.ncsu.edu/stormwater/PublicationFiles/ PermPave2008.pdf.

Interlocking Concrete Pavement Institute (ICPI). 2008. *Permeable Interlocking Concrete Pavement: A Comprison Guide to Porous Asphalt and Pervious Concrete.*

Jackson, N. 2007. *Design, Construction and Maintenance Guide for Porous Asphalt Pavements*. National Asphalt Pavement Association. Information Series 131. Lanham, MD. www.hotmix.com

Northern Virginia Regional Commission (NVRC). 2007. *Low Impact Development Supplement to the Northern Virginia BMP Handbook.* Fairfax, Virginia

Schueler, T., C. Swann, T. Wright and S. Sprinkle. 2004. *Pollution source control practices*. Manual No. 8 in the Urban Subwatershed Restoration Manual Series. Center for Watershed Protection. Ellicott City, MD.

Schueler et al 2007. *Urban Stormwater Retrofit Practices*. Manual 3 in the Urban Subwatershed Restoration Manual Series. Center for Watershed Protection. Ellicott City, MD.

Schueler, T. 2008. Technical Support for the Baywide Runoff Reduction Method. Chesapeake Stormwater Network. Baltimore, MD. www.chesapeakestormwater.net

Smith, D. 2006. *Permeable Interlocking Concrete Pavement-selection design, construction and maintenance. Third Edition*. Interlocking Concrete Pavement Institute. Herndon, VA.

U.S EPA. 2008. June 13 2008 Memo. L. Boornaizian and S. Heare. "Clarification on which stormwater infiltration practices/technologies have the potential to be regulated as "Class V" wells by the Underground Injection Control Program." Water Permits Division and Drinking Water Protection Division. Washington, D.C.

Virginia Department of Transportation (VDOT). 2003. *Guidelines for 1993 AASHTO Pavement Design*. VDOT Materials Division, Pavement Design and Evaluation Section. Richmond, VA. Available online at: http://www.virginiadot.org/business/resources/bu-mat-pde-AASHTOForConsultants0503.pdf

Water Environment Research Federation (WERF). 2005. *Performance and Whole-life Costs of Best Management Practices and Sustainable Urban Drainage Systems*. Alexandria, VA.

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 8

INFILTRATION PRACTICES

VERSION 1.9
March 1, 2011

SECTION 1: DESCRIPTION

Infiltration practices use temporary surface or underground storage to allow incoming stormwater runoff to exfiltrate into underlying soils. Runoff first passes through multiple pretreatment mechanisms to trap sediment and organic matter before it reaches the practice. As the stormwater penetrates the underlying soil, chemical and physical adsorption processes remove pollutants. Infiltration practices have the greatest runoff reduction capability of any stormwater practice and are suitable for use in residential and other urban areas where *measured* soil permeability rates exceed 1/2 inch per hour. To prevent possible groundwater contamination, infiltration should not be utilized at sites designated as stormwater hotspots.

SECTION 2: PERFORMANCE

When used appropriately, infiltration has a very high runoff volume reduction capability, as shown in **Table 8.1**.

Table 8.1. Summary of Stormwater Functions Provided by Infiltration

Stormwater Function	Level 1 Design	Level 2 Design
Annual Runoff Volume Reduction (RR)	50%	90%
Total Phosphorus (TP) EMC Reduction[1] by BMP Treatment Process	25%	25%
Total Phosphorus (TP) Mass Load Removal	63%	93%
Total Nitrogen (TN) EMC Reduction[1] by BMP Treatment Process	15%	15%
Total Nitrogen (TN) Mass Load Removal	57%	92%
Channel and Flood Protection	• Use the RRM spreadsheet to calculate the Curve Number (CN) adjustment; ***OR*** • Design for extra storage (optional; as needed) on the surface or in the subsurface storage volume to accommodate larger storm volumes, and use NRCS TR-55 Runoff Equations [2] to compute the CN Adjustment.	

[1] Change in the event mean concentration (EMC) through the practice. The actual nutrient mass load removed is the product of the removal rate and the runoff reduction (RR) rate (see Table 1 in the *Introduction to the New Virginia Stormwater Design Specifications*).
[2] NRCS TR-55 Runoff Equations 2-1 thru 2-5 and Figure 2-1 can be used to compute a curve number adjustment for larger storm events, based on the retention storage provided by the practice(s).

Sources: CWP and CSN (2008), and CWP (2007)

SECTION 3: DESIGN TABLE

The major design goal for Infiltration is to maximize runoff volume reduction and nutrient removal. To this end, designers may choose to go with the baseline design (Level 1) or choose an enhanced design (Level 2) that maximizes nutrient and runoff reduction. To qualify for Level 2, the infiltration practice must meet all the design criteria shown in the right hand column of **Table 8.2**.

Table 8.2. Level 1 and Level 2 Infiltration Design Guidelines

Level 1 Design (RR:50; TP:25; TN:15)	Level 2 Design (RR:90; TP:25; TN:15)
Sizing: $T_V = [(Rv)(A)/12]$ – the volume reduced by an upstream BMP	Sizing: $T_V = [1.1(Rv)(A)/12]$ – the volume reduced by an upstream BMP
At least two forms of pre-treatment (see **Table 8.6**)	At least three forms of pre-treatment (see **Table 8.6**)
Soil infiltration rate 1/2 to 1 in./hr. (see **Section 6.1** & **Appendix 8-A**); number of tests depends on the scale (Table 3)	Soil infiltration rates of 1.0 to 4.0 in/hr (see **Section 6.1** & **Appendix 8-A**); number of tests depends on the scale (**Table 8.3**)
Minimum of 2 feet between the bottom of the infiltration practice and the seasonal high water table or bedrock (**Section 4 5**)	
T_V infiltrates within 36 to 48 hours (**Section 6.6**)	
Building Setbacks – see **Table 8.3**	
All Designs are subject to hotspot runoff restrictions/prohibitions	

SECTION 4: TYPICAL DETAILS

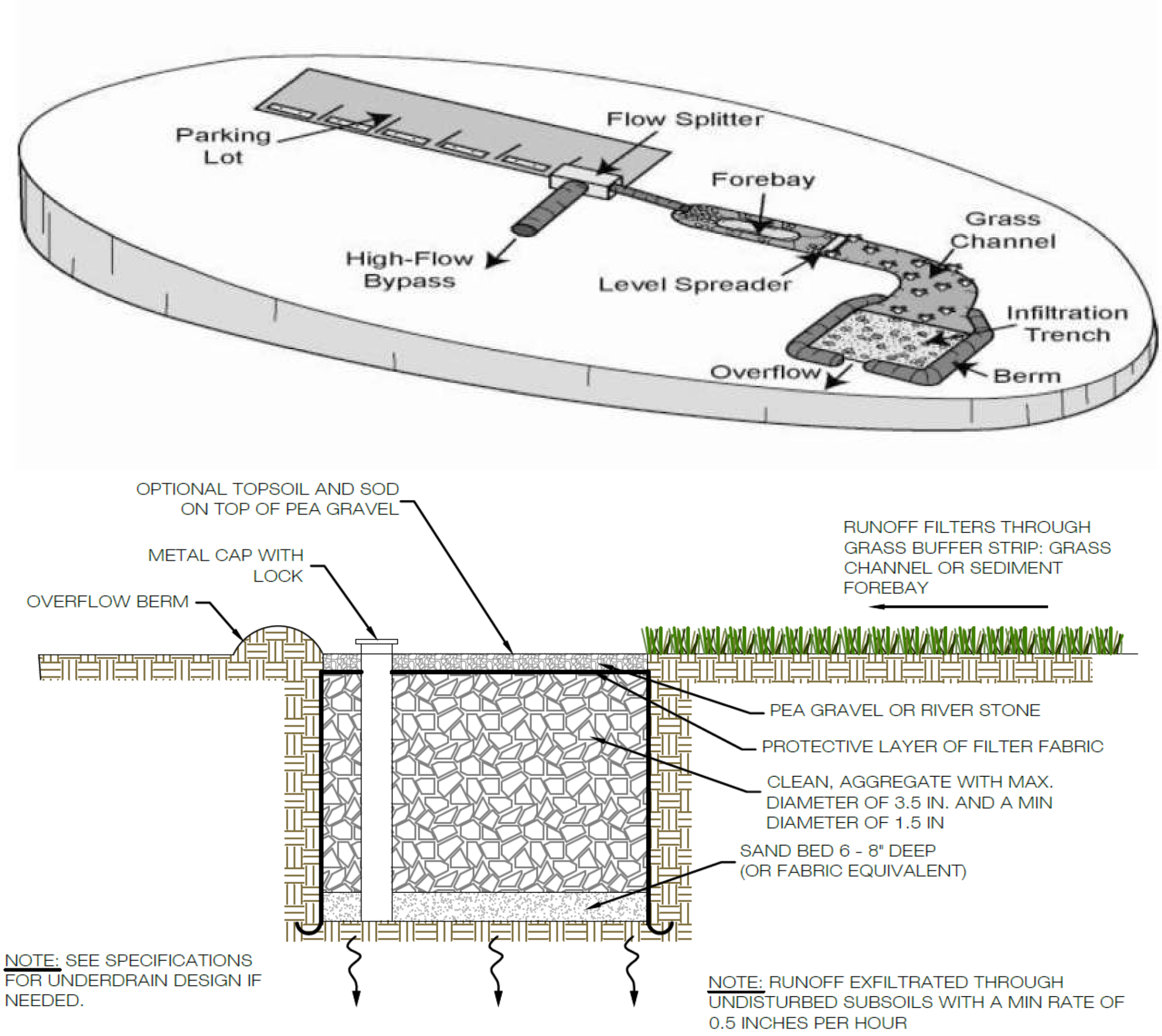


Figure 8.1. Infiltration Plan and Section

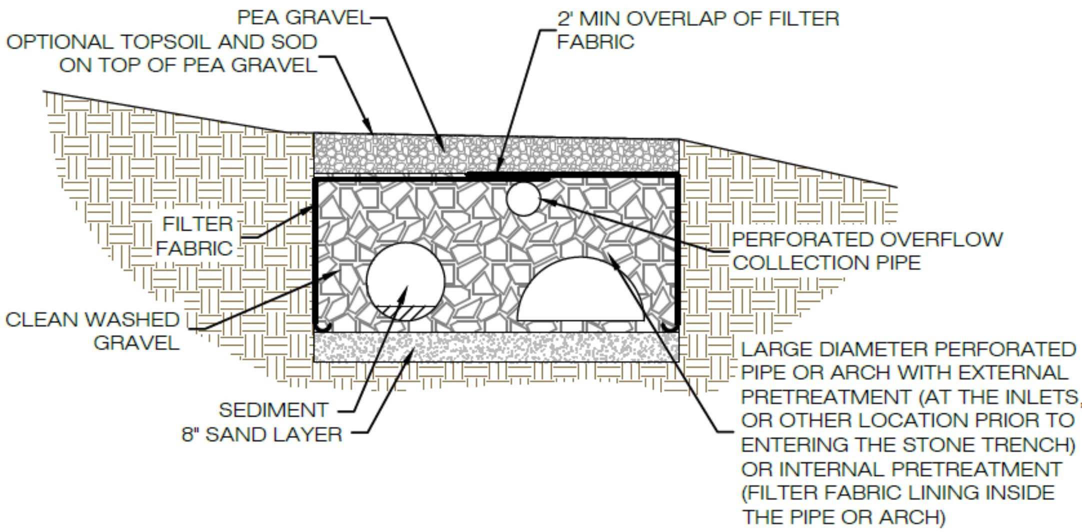


Figure 8.2A: Infiltration Section with Supplemental Pipe Storage

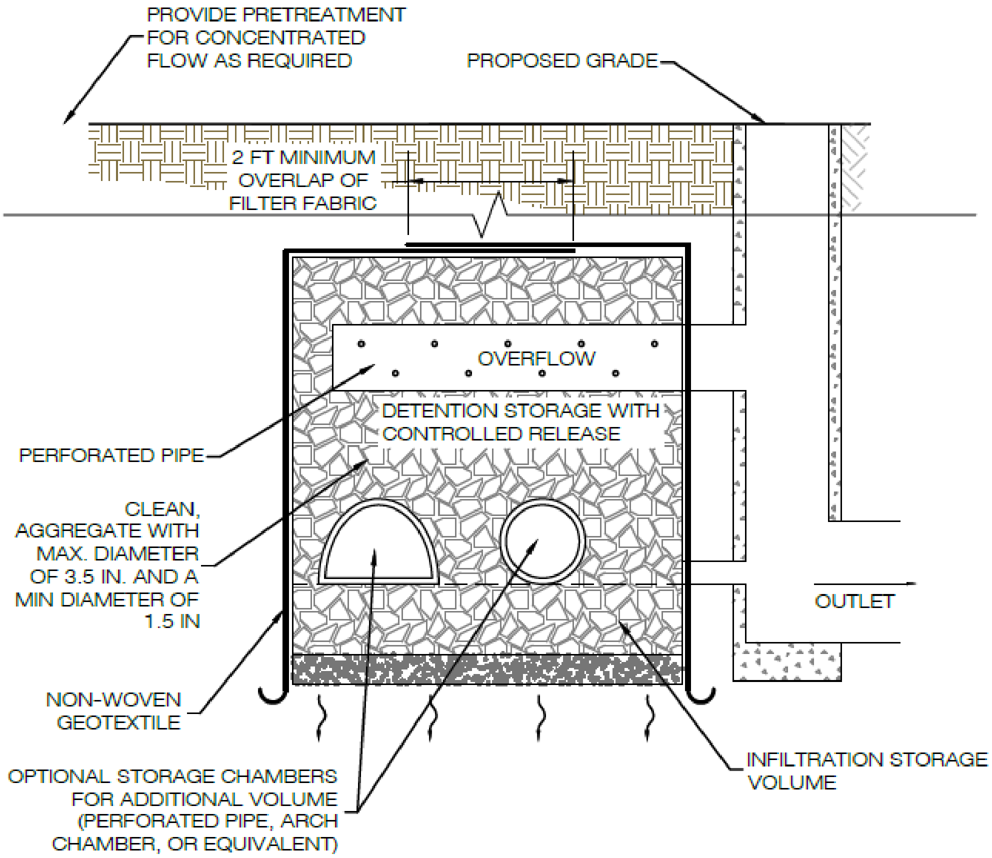


Figure 8.2B: Combined Underground Detention (Channel and/or Flooding Protection) and Infiltration

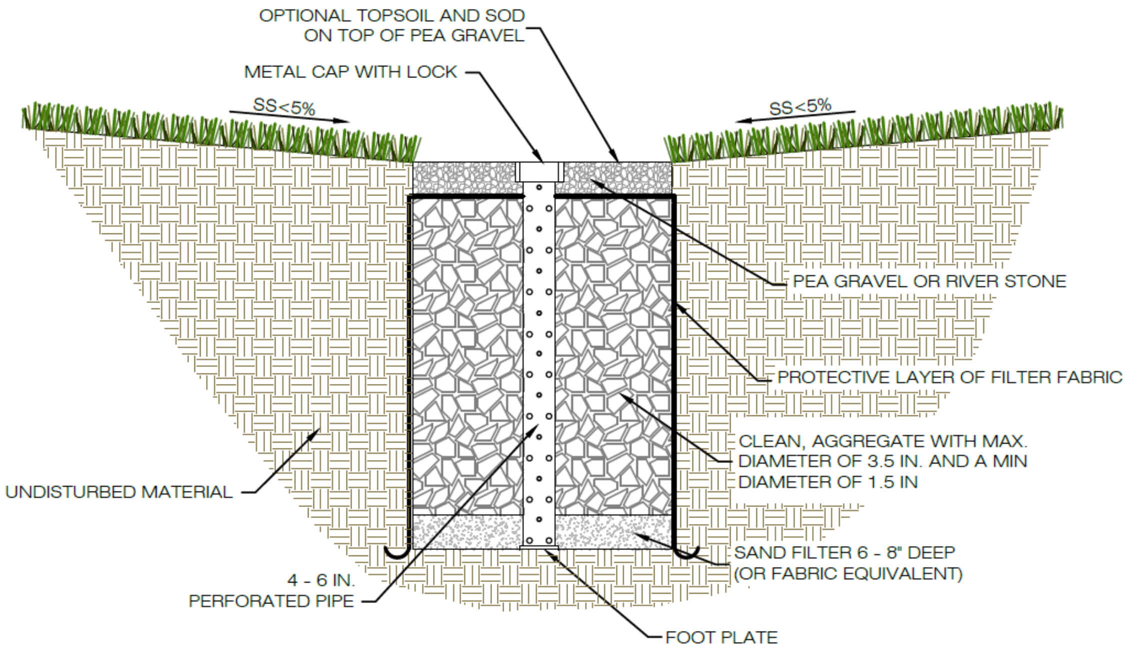


Figure 8.3: Observation Well

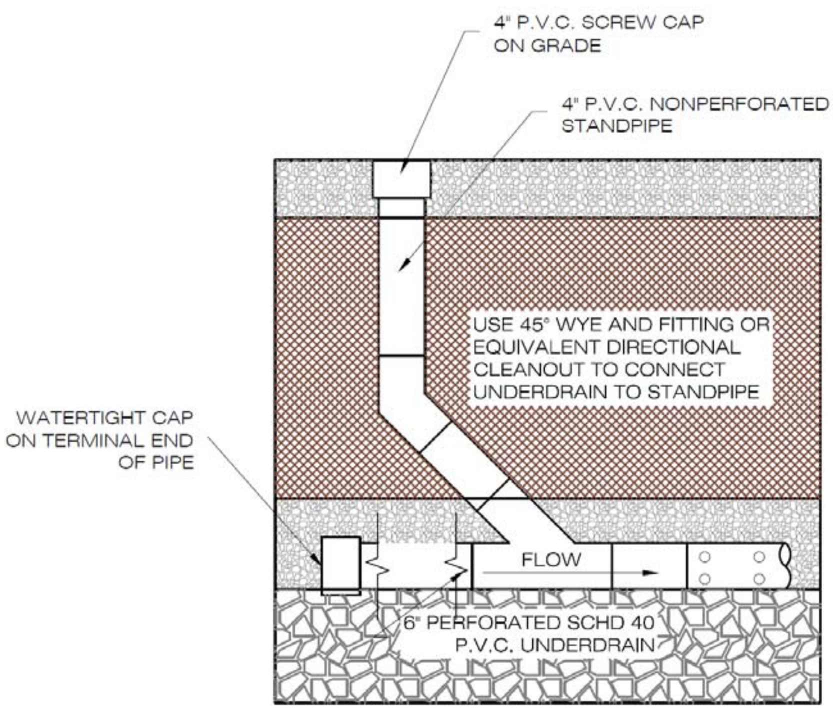


Figure 8.4: 4” PVC Cleanout

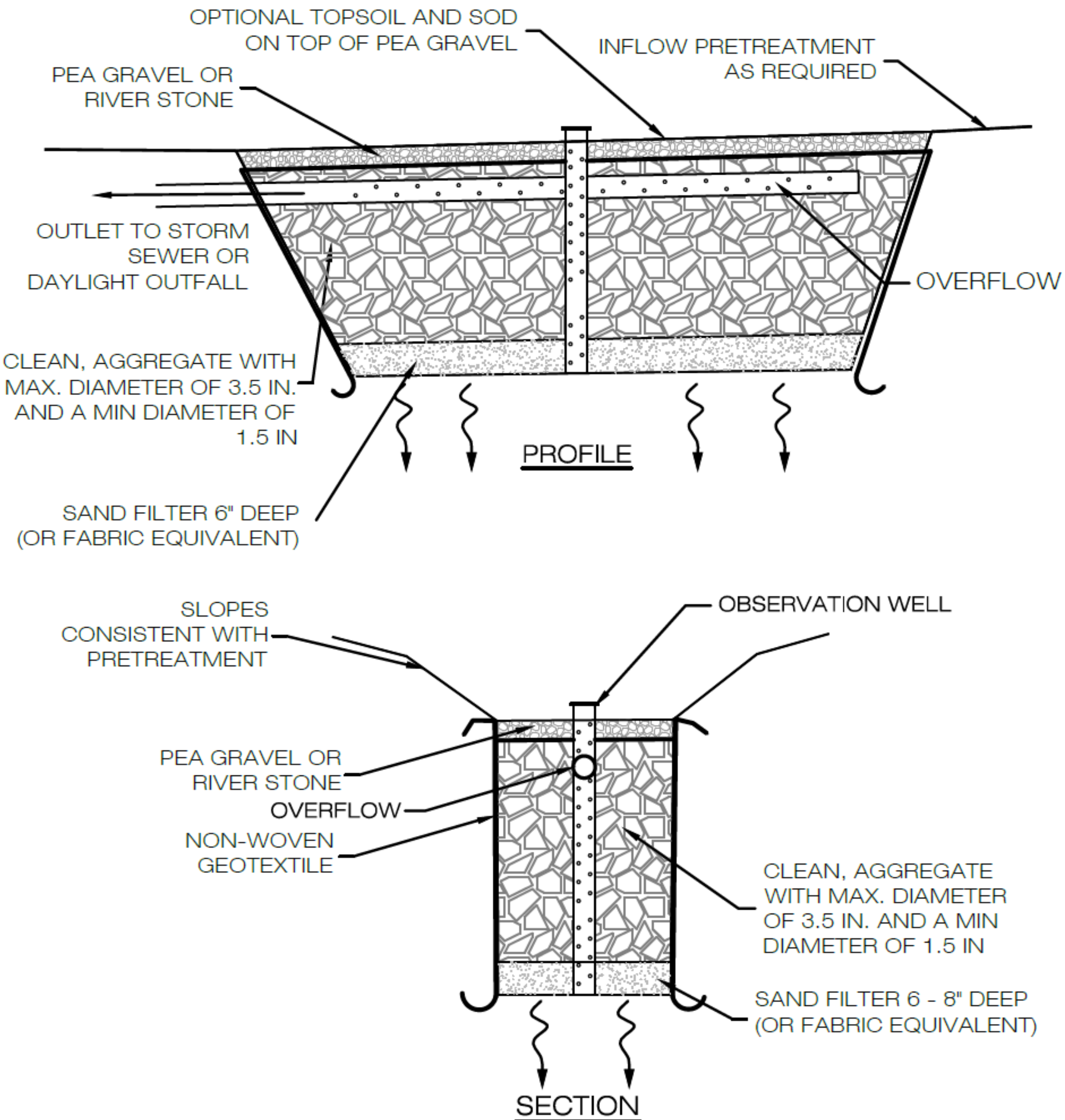


Figure 8.5: Typical Infiltration Trench

SECTION 5: PHYSICAL FEASIBILITY & DESIGN APPLICATIONS

Since infiltration practices have a very high runoff reduction capability, they should always be considered when initially evaluating a site. Designers should evaluate the range of soil properties during initial site layout and seek to configure the site to conserve and protect the soils with the greatest recharge and infiltration rates. In particular, areas of Hydrologic Soil Group A or B soils shown on NRCS soil surveys should be considered as primary locations for infiltration practices. At this point, designers should carefully identify and evaluate constraints on infiltration, as follows:

Contributing Drainage Area. The maximum contributing drainage area (CDA) to an individual infiltration practice should be less than 2 acres and as close to 100% impervious as possible. This specification covers three scales of infiltration practices (1) Micro-infiltration (250 to 2,500 sq. ft. of CDA), (2) small-scale infiltration (2,500 to 20,000 sq. ft. of CDA) and (3) conventional infiltration (20,000 to 100,000 sq. ft. of CDA). The design, pretreatment and maintenance requirements differ, depending on the scale at which infiltration is applied (see **Table 8.3** below for a summary).

Table 8.3. The Three Design Scales for Infiltration Practices

Design Factor	Micro-Infiltration	Small-Scale Infiltration	Conventional Infiltration
Impervious Area Treated	250 to 2,500 sq. ft.	2,500 to 20,000 sq. ft.	20,000 to 100,000 sq. ft.
Typical Practices	Dry Well French Drain Paving Blocks	Infiltration Trench Permeable Paving [1]	Infiltration Trench Infiltration Basin
Min.Infiltration Rate	1/2 inch/hour		
Design Infil. Rate	50% of measured rate		
Observation Well	No	Yes	Yes
Type of Pretreatment (see **Table 8.6**)	External (leaf screens, grass filter strip, etc)	Vegetated filter strip or grass channel, forebay, etc.	Pretreatment Cell
Depth Dimensions	Max. 3-foot depth	Max. 5-foot depth	Max. 6-foot depth,
UIC Permit Needed	No	No	Only if the surface width is less than the max. depth
Head Required	Nominal: 1 to 3 feet	Moderate: 1 to 5 feet	Moderate: 2 to 6 feet
Underdrain Requirements?	An elevated underdrain only on marginal soils	None required	Back up underdrain
Required Soil Tests	One per practice	One (1) per 1,000 sq. ft. of surface area or max. two (2) per practice.	One per 1,000 sq. ft. of surface area.
Building Setbacks	5 feet down-gradient [2] 25 feet up-gradient	10 feet down-gradient 50 feet up-gradient	25 feet down-gradient 100 feet up-gradient

[1] Although permeable pavement is an infiltration practice, a more detailed specification is provided in Stormwater Design Specification No. 7.

[2] Note that the building setback of 5 feet is intended for simple foundations. The use of a dry well or french drain adjacent to an in-ground basement or finished floor area should be carefully designed and coordinated with the design of the structure's water-proofing system (foundation drains, etc.), or avoided altogether.

Site Topography. Unless slope stability calculations demonstrate otherwise, infiltration practices should be located a minimum horizontal distance of 200 feet from down-gradient slopes greater than 20%. The average slope of the contributing drainage areas should be less than 15%.

Practice Slope. The bottom of an infiltration practice should be flat (i.e., 0% longitudinal slope) to enable even distribution and infiltration of stormwater, although a maximum longitudinal slope of 1% is permissible if an underdrain is employed. Lateral slopes should be 0%.

Minimum Hydraulic Head. The elevation difference needed to operate a micro-scale infiltration practice is nominal. However, 2 or more feet of head may be needed to drive small-scale and conventional infiltration practices.

Minimum Depth to Water Table or Bedrock. A minimum vertical distance of 2 feet must be provided between the bottom of the infiltration practice and the seasonal high water table or bedrock layer.

Soils. Native soils in proposed infiltration areas must have a minimum infiltration rate of 1/2 inch per hour (typically Hydrologic Soil Group A and B soils meet this criterion). Initially, soil infiltration rates can be estimated from NRCS soil data, but they must be confirmed by an on-site infiltration evaluation. Native soils must have silt/clay content less than 40% and clay content less than 20%.

Use on Urban Soils/Redevelopment Sites. Sites that have been previously graded or disturbed do not retain their original soil permeability due to compaction. Therefore, such sites are not good candidates for infiltration practices. In addition, *i*nfiltration practices should never be situated above fill soils.

Dry Weather Flows. Infiltration practices should not be used on sites receiving regular dry-weather flows from sump pumps, irrigation nuisance water, and similar kinds of flows.

Setbacks. Infiltration practices should not be hydraulically connected to structure foundations or pavement, in order to avoid harmful seepage. Setbacks to structures and roads vary based on the scale of infiltration (see **Table 8.1** above). At a minimum, conventional and small-scale infiltration practices should be located a minimum horizontal distance of 100 feet from any water supply well, 50 feet from septic systems, and at least 5 feet down-gradient from dry or wet utility lines.

High Loading Situations. Infiltration practices are *not* intended to treat sites with high sediment or trash/debris loads, because such loads will cause the practice to clog and fail.

Groundwater Protection. **Section 10** of this specification presents a list of potential stormwater hotspots that pose a risk of groundwater contamination. Infiltration of runoff from designated hotspots is highly restricted or prohibited.

Site-Specific Considerations. Infiltration practices can be applied to most land uses that have measured soil infiltration rates that exceed 1/2 inch per hour. However, there is no single infiltration application that fits every development situation. The nature of the actual design application depends on four key design factors, described below:

1. The first factor is the **Design Scale** at which infiltration will be applied:
   - **Micro-infiltration** is intended for residential rooftop disconnection, rooftop rainwater harvesting systems, or other small scale application (250 to 2,500 sq. ft. of impervious area treated);

- **Small-scale infiltration** is intended for residential and/or small commercial applications that meet the feasibility criteria noted above; and
- **Conventional infiltration** can be considered for most typical development and redevelopment applications and therefore has more rigorous site selection and feasibility criteria.

Table 8.3 above compares the different design approaches and requirements associated with each infiltration scale.

2. The second key design factor relates to the **mode** (or method) of temporarily storing runoff prior to infiltration – either on the surface or in an underground trench. When storing runoff on the surface (e.g., an infiltration basin), the maximum depth should be no greater than 1 foot. However, if pretreatment cells are used, a maximum depth of 2 feet is permissible. In the underground mode, runoff is stored in the voids of the stones, and infiltrates into the underlying soil matrix. Perforated corrugated metal pipe, plastic pipe, concrete arch pipe, or comparable materials can be used in conjunction with the stone to increase the available temporary underground storage. In some instances, a combination of filtration and infiltration cells can be installed in the floor of a dry extended detention (ED) pond.

3. The third design factor relates to the degree of **confidence that exfiltration can be maintained** over time, given the measured infiltration rate for the subsoils at the practice location and the anticipated land uses. This determines whether an underdrain is needed, or whether an alternative practice, such as bioretention, is needed at the site (see **Table 8.4** below).

Table 8.4. Design Choices Based on Measured Infiltration Rate

	Measured Infiltration Rate (inches/hour)			
	Less than 1/2	***1/2 to 1***	***1 to 4***	***More than 4***
Recommended Design Solution	Use Bioretention or a Dry Swale with an underdrain.	Use Infiltration without an underdrain, or with a 12-inch stone reservoir below the underdrain invert. Alternately, use Bioretention with an elevated underdrain.	Use Infiltration, Bioretention, or a Dry Swale without an underdrain.	Use Infiltration, Bioretention, or a Dry Swale without an underdrain.

4. The final factor is whether the infiltration practice will be designed as an **on-line or off-line facility**, as this determines the nature of conveyance and overflow mechanisms needed. Off-line practices are sized to only accept some portion of the treatment volume, and employ a flow splitter to safely bypass large storms. On-line infiltration practices may be connected to underground perforated pipes to detain the peak storm event, or have suitable overflows to pass the storms without erosion.

SECTION 6: DESIGN CRITERIA

6.1. Defining the Infiltration Rate

Soil permeability is the single most important factor when evaluating infiltration practices. A field-verified minimum infiltration rate of *at least* 1/2 inch/hour is needed for the practice to work.

Projected Infiltration Rate. For planning purposes, the projected infiltration rate for the site can be estimated using the NRCS soil textural triangle for the prevailing soil types shown on the local NRCS Soil Survey. This data is used solely to locate portions of the site where infiltration may be feasible and to pinpoint where actual on-site infiltration tests will be taken to confirm feasibility.

Measured Infiltration Rate. On-site infiltration investigations should always be conducted to establish the actual infiltration capacity of underlying soils, using the methods presented in **Appendix 8-A**.

Design Infiltration Rate. Several studies have shown that ultimate infiltration rates decline by as much as 50% from initial rates, so designers should be very conservative and not attempt to use infiltration on questionable soils. To provide a factor of safety, the infiltration rate used in the design may be no greater than 50% of the measured rate.

6.2. Sizing of Infiltration Facilities

Several equations are needed to size infiltration practices. The first equations establish the maximum depth of the infiltration practice, depending on whether it is a surface basin (**Equation 8.1**)or underground reservoir (**Equation 8.2**).

Equation 8.1. Maximum Surface Basin Depth

$$d_{\max} = \tfrac{1}{2} f \times t_d$$

Equation 8.2. Maximum Underground Reservoir Depth

$$d_{\max} = \frac{\{1/2\, f \times t_d\}}{V_r}$$

Where:

d_{max}	=	maximum depth of the infiltration practice (feet)
f	=	measured infiltration rate (ft./day)
t_d	=	maximum drawn down time (normally 1.5 to 2 days) (day)
Vr	=	void ratio of the stone reservoir (assume 0.4)

Designers should compare these results to the maximum allowable depths in **Table 8.5**, and use whichever value is *less* for subsequent design.

Table 8.5. Maximum Depth (in feet) for Infiltration Practices

Mode of Entry	Scale of Infiltration		
	Micro Infiltration	Small Scale Infiltration	Conventional Infiltration
Surface Basin	1.0	1.5	2.0
Underground Reservoir	3.0	5.0	varies

Once the maximum depth is known, then calculate the surface area needed for an infiltration practice using **Equation 8.3** or **Equation 8.4**:

Equation 8.3. Surface Basin Surface Area

$$SA = TV / (d + ½ f * t_f)$$

Equation 8.4. Underground Reservoir Surface Area

$$SA = TV / (Vr * d + ½ f * t_f)$$

Where:

SA	=	Surface area (sq. ft.)
TV	=	Design volume (e.g., portion of the treatment volume, in cu. ft.)
V_r	=	Void Ratio (assume 0.4)
d	=	Infiltration depth (maximum depends on the scale of infiltration and the results of **Equation 8.1** (ft.)
f	=	Measured infiltration rate (ft./day)
t_f	=	Time to fill the infiltration facility (days – typically 2 hours, or 0.083 days)

If the designer~~s~~ chooses to infiltrate less than the full Treatment Volume (e.g., through the use of micro-infiltration or small-scale infiltration), the runoff reduction rates shown in **Table 8.6** below must be directly prorated in the Runoff Reduction Method (RRM) spreadsheet. To qualify for Level 2 runoff reduction rates, designers must provide 110% of the site-adjusted Treatment Volume.

6.3. Soil Infiltration Rate Testing

The acceptable methods for on-site soil infiltration rate testing procedures are outlined in **Appendix 8-A**. Since soil infiltration properties can vary, the different scales of infiltration should be tested according to the following recommendations:

- ***Micro-infiltration*:** One test per facility
- ***Small-Scale Infiltration*:** One per 1,000 sq. ft of surface area, or a maximum of two tests per facility
- ***Conventional Infiltration*:** One test per 1,000 sq. ft. of proposed infiltration bed

6.4. Pretreatment Features

Every infiltration practice must include multiple pretreatment techniques, although the nature of pretreatment practices depends on the scale at which infiltration is applied. The number, volume and type of acceptable pretreatment techniques needed for the three scales of infiltration are provided in **Table 8.6**.

Table 8.6. Required Pretreatment Elements for Infiltration Practices

Pretreatment [1]	**Scale of Infiltration**		
	Micro Infiltration	**Small-Scale Infiltration**	**Conventional Infiltration**
Number and Volume of Pretreatment Techniques Employed	**2** external techniques; no minimum pretreatment volume required.	**3** techniques; **15%** minimum pretreatment volume required (inclusive).	**3** techniques; **25%** minimum pretreatment volume required (inclusive); at least **one** separate pre-treatment cell.
Acceptable Pretreatment Techniques[2]	Leaf gutter screens Grass filter strip Upper sand layer Washed bank run gravel	Grass filter strip Grass channel Plunge pool Gravel diaphragm	Sediment trap cell Sand filter cell Sump pit Grass filter strip Gravel diaphragm
[1] A minimum of 50% of the runoff reduction volume must be pre-treated by a filtering or bioretention practice *prior* to infiltration *if* the site is a restricted stormwater hotspot			

Note that conventional infiltration practices require pretreatment of at least 25% of the treatment volume, including a surface pretreatment cell capable of keeping sediment and vegetation out of the infiltration cell. All pretreatment practices should be designed such that exit velocities are non-erosive for the two year design storm and evenly distribute flows across the width of the practice (e.g., using a level spreader).

6.5. Conveyance and Overflow

The nature of the conveyance and overflow to an infiltration practice depends on the scale of infiltration and whether the facility is on-line or off-line (**Table 8.7**). Where possible, conventional infiltration practices should be designed offline to avoid damage from the erosive velocities of larger design storms. Micro-scale and small-scale infiltration practices ~~shall~~ must be designed to maintain non-erosive conditions for overland flows generated by the 2-year design storm (typically 3.5 to 5.0 feet per second).

Table 8.7. Conveyance and Overflow Choices Based on Infiltration Scale

Conveyance and Overflow	Scale of Infiltration		
	Micro-Infiltration	Small-Scale Infiltration	Conventional Infiltration
Online Design	Discharge to a non-erosive pervious overland flow path designed to convey the 2-year design storm to the street or storm drain system.	An overflow mechanism such as an elevated drop inlet or flow splitter should be used to redirect flows to a non-erosive down-slope overflow channel or stabilized water course designed to convey the 10-year design storm.	
Off-line Design	Not Recommended	A flow splitter or overflow structure can be used for this purpose using design guidance in Claytor and Schueler (1996) and ARC (2001).	

6.6. Internal Geometry and Drawdowns

Runoff Reduction Volume Sizing. The proper approach for designing infiltration practices is to avoid forceing a large amount of infiltration into a small area. Therefore, individual infiltration practices that are limited in size due to soil permeability and available space need not be sized to achieve the full Treatment Volume for the contributing drainage area, as long as other runoff reduction practices are applied at the site to meet the remainder of the T_v. The total runoff reduction volume must be documented using the Runoff Reduction Method spreadsheet or another locally approved methodology that achieves equivalent results. The minimum amount of runoff from a given drainage area that can be treated by individual infiltration practices is noted in **Table 8.2** above.

Infiltration Basin Restrictions. The maximum vertical depth to which runoff may be ponded over an infiltration area is 24 inches (i.e., infiltration basin). The side-slopes should be no steeper than 4H:1V, and if the basin serves a CDA greater than 20,000 sq. ft., a surface pre-treatment cell must be provided (this may be sand filter or dry sediment basin).

Rapid Drawdown. When possible, infiltration practices should be sized so that the target runoff reduction volume infiltrates within 36 hours to 48 hours, to provide a factor of safety that prevents nuisance ponding conditions.

Conservative Infiltration Rates. Designers should always use the design infiltration rate, rather than the measured infiltration rate, to approximate long term infiltration rates (see **Section 6.1** above).

Void Ratio. A porosity value of 0.40 shall be used in the design of stone reservoirs, although a larger value may be used if perforated corrugated metal pipe, plastic pipe, concrete arch pipe, or comparable materials are installed within the reservoir.

6.7. Landscaping and Safety

Infiltration trenches can be effectively integrated into the site plan and aesthetically designed with adjacent native landscaping or turf cover, subject to the following additional design considerations:

- Infiltration practices should *NEVER* be installed until all up-gradient construction is completed *AND* pervious areas are stabilized with dense and healthy vegetation.
- Vegetation associated with the infiltration practice buffers should be regularly mowed and maintained to keep organic matter out of the infiltration device and maintain enough native vegetation to prevent soil erosion from occurring.
- Infiltration practices do not pose any major safety hazards after construction. However, if an infiltration practice will be excavated to a depth greater than 5 feet, OSHA health and safety guidelines shall be followed for safe construction practices.
- Fencing of infiltration trenches is neither necessary nor desirable.

Designers should always evaluate the nature of future operations to determine if the proposed site will be designated as a potential stormwater hotspot (see **Section 10.1**), and comply with the appropriate restrictions or prohibitions applicable to infiltration.

6.8. Maintenance Reduction Features

Maintenance is a crucial element that ensures the long-term performance of infiltration practices. The most frequently cited maintenance problem for infiltration practices is clogging of the stone by organic matter and sediment. The following design features can minimize the risk of clogging:

Observation Well. Small-scale and conventional infiltration practices should include an observation well, consisting of an anchored 6-inch diameter perforated PVC pipe fitted with a lockable cap installed flush with the ground surface, to facilitate periodic inspection and maintenance.

No Filter Fabric on Bottom. Avoid installing geotextile filter fabric along the bottom of infiltration practices. Experience has shown that filter fabric is prone to clogging, and a layer of coarse washed stone (choker stone) is a more effective substitute. However, permeable filter fabric must be installed on the trench sides to prevent soil piping.

Direct Maintenance Access. Access must be provided to allow personnel and heavy equipment to perform non-routine maintenance tasks, such as practice reconstruction or rehabilitation. While a turf cover is permissible for micro- and small-scale infiltration practices, the surface must never be covered by an impermeable material, such as asphalt or concrete.

6.9. Infiltration Material Specifications

The basic material specifications for infiltration practices are outlined in **Table 8.8** below.

Table 8.8. Infiltration Material Specifications

Material	Specification	Notes
Stone	Clean, aggregate with a maximum diameter of 3.5 inches and a minimum diameter of 1.5 inches (VDOT No. 1 Open-Graded Coarse Aggregate) or the equivalent.	
Observation Well	Install a vertical 6-inch Schedule 40 PVC perforated pipe, with a lockable cap and anchor plate.	Install one per 50 feet of length of infiltration the practice.
Trench Bottom	Install a 6 to 8 inch sand layer (VDOT Fine Aggregate, Grade A or B)	
Trench Surface Cover	Install a 3-inch layer of river stone or pea gravel. Turf is acceptable when there is subsurface inflow (e.g., a roof leader).	This provides an attractive surface cover that can suppress weed growth.
Buffer Vegetation	Keep adjacent vegetation from forming an overhead canopy above infiltration practices, in order to keep leaf litter, fruits and other vegetative material from clogging the stone.	
Filter Fabric (sides only)	Use non-woven polyprene geotextile with a flow rate of > 110 gallons/min./sq. ft. (e.g., Geotex 351 or equivalent).	
Choking Layer	Install a 2- to 4-inch layer of choker stone (typically #8 or # 89 washed gravel) over the underdrain stone.	
Underdrain (where needed)	Use 6-inch rigid schedule 40 PVC pipe, with 3/8" perforations at 6 inches on center, with each perforated underdrain, installed at a slope of 1% for the length of the infiltration practice.	Install non-perforated pipe with one or more caps, as needed. from the downspout to a point 15 feet from the structure. Install T's as needed for the underdrain configuration.
Stone Jacket for Underdrain	The stone should be double-washed and clean and free of all soil and fines.	Install a minimum of 3 inches of # 57 stone above the underdrain and a minimum of 12 inches below it.

SECTION 7: REGIONAL & SPECIAL CASE DESIGN ADAPTATIONS

7.1. Karst Terrain

Conventional infiltration practices **should not be used** in karst regions due to concerns about sinkhole formation and groundwater contamination. Micro- or small-scale infiltration areas are permissible *IF* geotechnical studies indicate there is at least 4 feet of vertical separation between the bottom of the infiltration facilities and the underlying karst layer *AND* an impermeable liner and underdrain are used. In many cases, bioretention is a preferred stormwater management alternative to infiltration in karst areas.

7.2. Coastal Plain

The flat terrain, low head and high water table of many coastal plain sites can constrain the application of conventional infiltration practices. However, such sites are still suited for micro-scale and small-scale infiltration practices. Designers should maximize the surface area of the infiltration practice, and keep the depth of infiltration to less than 24 inches. Where soils are extremely permeable (more than 4.0 inches per hour), shallow bioretention is a preferred alternative. Where soils are more impermeable (i.e., marine clays with less than 0.5 inches per hour), designers may prefer to use a constructed wetland practice.

7.3. Steep Terrain

Forcing conventional infiltration practices in steep terrain can be problematic with respect to slope stability, excessive hydraulic gradients and sediment delivery. Unless slope stability calculations demonstrate otherwise, it is generally recommended that infiltration practices should be located a minimum horizontal distance of 200 feet from down-gradient slopes greater than 20%. Micro-scale and small-scale infiltration can work well, as long as their smaller up-gradient and down-gradient building setbacks are satisfied.

7.4. Cold Climate and Winter Performance

Infiltration practices can be designed to withstand more moderate winter conditions. The main problem is caused by ice forming in the voids or the subsoils below the practice, which may briefly result in nuisance flooding when spring melting occurs. The following design adjustments are recommended for infiltration practices installed in higher elevations:

- The bottom of the practice should extend below the frost line.
- Infiltration practices are not recommended at roadside locations that are heavily sanded and/or salted in the winter months (to prevent movement of chlorides into groundwater and prevent clogging by road sand).
- Pre-treatment measures can be oversized to account for the additional sediment load caused by road sanding (up to 40% of the Treatment Volume).
- Infiltration practices must be set back at least 25 feet from roadways to prevent potential frost heaving of the road pavement.

7.5. Linear Highway Sites

Infiltration practices can work well for linear highway projects, where soils are suitable and can be protected from heavy disturbance and compaction during road construction operations.

SECTION 8: CONSTRUCTION

8.1. Construction Sequence

The following is a typical construction sequence to properly install infiltration practices. The sequence may need to be modified to reflect the scale of infiltration, site conditions, and whether or not an underdrain needs to be installed.

Infiltration practices are particularly vulnerable to failure during the construction phase for two reasons. First, if the construction sequence is not followed correctly, construction sediment can clog the practice. In addition, heavy construction can result in compaction of the soil, which can then reduce the soil’s infiltration rate. For this reason, a careful construction sequence needs to be followed.

During site construction, the following steps are absolutely critical:

- Avoid excessive compaction by preventing construction equipment and vehicles from traveling over the proposed location of the infiltration practice.
- Keep the infiltration practice "off-line" until construction is complete. Prevent sediment from entering the infiltration site by using super silt fence, diversion berms or other means. In the erosion and sediment (E&S) control plan, indicate the earliest time at which stormwater runoff may be directed to a conventional infiltration basin The E&S control plan must also indicate the specific methods to be used to temporarily keep runoff from the infiltration site.
- Infiltration practice sites should never serve as the sites for temporary sediment control devices (e.g., sediment traps, etc.) during construction.
- Upland drainage areas need to be completely stabilized with a thick layer of vegetation prior to commencing excavation for an infiltration practice, as verified by the local erosion and sediment control inspector/program.

The actual installation of an infiltration practice is done using the following steps:

1. Excavate the infiltration practice to the design dimensions *from the side*, using a backhoe or excavator. The floor of the pit should be completely level, but equipment should be kept off the floor area to prevent soil compaction.

2. Correctly install filter fabric on the trench sides. Large tree roots should be trimmed flush with the sides of infiltration trenches to prevent puncturing or tearing of the filter fabric during subsequent installation procedures. When laying out the geotextile, the width should include sufficient material to compensate for perimeter irregularities in the trench and for a 6-inch minimum overlap at the top of the trench. The filter fabric itself should be tucked under the sand layer on the bottom of the infiltration trench. Stones or other anchoring objects should be placed on the fabric at the trench sides, to keep the trench open during windy periods. Voids may occur between the fabric and the excavated sides of a trench. Natural soils should be placed in all voids, to ensure the fabric conforms smoothly to the sides of excavation.

3. Scarify the bottom of the infiltration practice, and spread 6 inches of sand on the bottom as a filter layer.

4. Install the underdrain, if one is needed.

5. Anchor the observation well(s), and add stone to the practice in 1-foot lifts.

6. Use sod to establish a dense turf cover for at least 10 feet on each side of the infiltration practice, to reduce erosion and sloughing. If the vegetation is seeded instead, use native grasses primarily due to their adaptability to local climates and soil conditions.

8.2. Construction Inspection

Inspections are needed during construction to ensure that the infiltration practice is built in accordance with the approved design and this specification. Qualified individuals should use detailed inspection checklists to include sign-offs at critical stages of construction, to ensure that the contractor's interpretation of the plan is consistent with the designer's intentions. An example construction phase inspection checklist for Infiltration practices can be accessed at the CWP website at:

http://www.cwp.org/Resource_Library/Controlling_Runoff_and_Discharges/sm.htm
(scroll to Tool6: Plan Review, BMP Construction, and Maintenance Checklists)

SECTION 9: MAINTENANCE

9.1. Maintenance Agreements

Section 4 VAC 50-60-124 of the regulations specifies the circumstances under which a maintenance agreement must be executed between the owner and the local program. This section sets forth inspection requirements, compliance procedures if maintenance is neglected, notification of the local program upon transfer of ownership, and right-of-entry for local program personnel.

When micro-scale or small-scale infiltration practices are installed on private residential lots, homeowners will need to (1) be educated about their routine maintenance needs, (2) understand the long-term maintenance plan, and (3) be subject to a deed restriction, drainage easement or other mechanism enforceable by the qualifying local program to ensure that infiltrating areas are not converted or disturbed. The mechanism should, if possible, grant authority for local agencies to access the property for inspection or corrective action. In addition, the GPS coordinates should be logged for all infiltration practices, upon facility acceptance, and submitted for entry into the local BMP maintenance tracking database.

9.2. Maintenance Inspections

Annual site inspections are critical to the performance and longevity of infiltration practices, particularly for small-scale and conventional infiltration practices. Maintenance of infiltration practices is driven by annual inspections that evaluate the condition and performance of the practices, including the following:

- The drawdown rate should be measured at the observation well for three days following a storm event in excess of 1/2 inch in depth. If standing water is still observed in the well after three days, this is a clear sign that that clogging is a problem.
- Check inlets, pre-treatment cells, and any flow diversion structures for sediment buildup and structural damage. Note if any sediment needs to be removed.
- Inspect the condition of the observation well and make sure it is still capped.
- Check that no vegetation forms an overhead canopy that may drop leaf litter, fruits and other vegetative materials that could clog the infiltration device.

- Evaluate the vegetative quality of the adjacent grass buffer and peform spot-reseeding if the cover density is less than 90%.
- Generally inspect the upland CDA for any controllable sources of sediment or erosion.
- Look for weedy growth on the stone surface that might indicate sediment deposition or clogging.
- Inspect maintenance access to ensure it is free of woody vegetation, and check to see whether valves, manholes and/or locks can be opened and operated.
- Inspect internal and external infiltration side slopes for evidence of sparse vegetative cover, erosion or slumping, and make necessary repairs immediately.

Based on inspection results, specific maintenance tasks will be triggered. Example maintenance inspection checklists for Infiltration practices can be accessed in Appendix C of Chapter 9 of the *Virginia Stormwater Management Handbook* (2010) or at the CWP website at:

http://www.cwp.org/Resource_Library/Controlling_Runoff_and_Discharges/sm.htm
(scroll to Tool6: Plan Review, BMP Construction, and Maintenance Checklists)

9.3. Ongoing Maintenance

Effective long-term operation of infiltration practices requires a dedicated and routine maintenance inspection schedule with clear guidelines and schedules, as shown in **Table 8.9** below. Where possible, facility maintenance should be integrated into routine landscaping maintenance tasks.

Table 8.9. Typical Maintenance Activities for Infiltration Practices

Maintenance Activity	Schedule
• Replace pea gravel/topsoil and top surface filter fabric (when clogged). • Mow vegetated filter strips as necessary and remove the clippings.	As needed
• Ensure that the contributing drainage area, inlets, and facility surface are clear of debris. • Ensure that the contributing drainage area is stabilized. • Remove sediment and oil/grease from pre-treatment devices, as well as from overflow structures. • Repair undercut and eroded areas at inflow and outflow structures.	Quarterly
• Check observation wells 3 days after a storm event in excess of 1/2 inch in depth. Standing water observed in the well after three days is a clear indication of clogging. • Inspect pre-treatment devices and diversion structures for sediment build-up and structural damage. • Remove trees that start to grow in the vicinity of the infiltration facility.	Semi-annual inspection
• Clean out accumulated sediments from the pre-treatment cell.	Annually

SECTION 10: COMMUNITY & ENVIRONMENTAL CONCERNS

10.1. Designation of Stormwater Hotspots

Stormwater hotspots are operations or activities that are known to produce higher concentrations of stormwater pollutants and/or have a greater risk for spills, leaks or illicit discharges. **Table 8.10** presents a list of potential land uses or operations that may be designated as a **stormwater hotspot**. It should be noted that the actual hotspot generating area may only occupy a portion of the entire proposed use, and that some "clean" areas (such as rooftops) can be diverted away to another infiltration or runoff reduction practice. Communities should carefully review development proposals to determine if any future operation, on all or part of the site, will be designated as a potential stormwater hotspot. Based on this designation, one or more design responses are required, as shown below:

1. ***Stormwater Pollution Prevention Plan (SWPPP)***. The SWPPP, required as part of a VPDES industrial activity or a municipal stormwater permit, outlines pollution prevention and treatment practices that will be implemented to minimize polluted discharges from the on-going operations of the facility. (NOTE: This is different from the SWPPP required as part of regulated construction activities.) Other facilities or operations that are not classified as industrial activities (SIC Codes) are not required to have an Industrial VPDES permit, but may still be designated as potential stormwater hotspots by the local review authority, as part of their local stormwater ordinance (these are shown in the shaded areas of **Table 8.10**). It is recommended that these facilities include an addendum to their stormwater plan that details the pollution prevention practices and employee training measures that will be used to reduce contact of pollutants with rainfall or snowmelt.

2. ***Restricted Infiltration***. A minimum of 50% of the total Treatment Volume must be treated by a filtering or bioretention practice prior to any infiltration. Portions of the site that are not associated with the hotspot generating area should be diverted away and treated by another acceptable stormwater management practice.

3. ***Infiltration Prohibition.*** The risk of groundwater contamination from spills, leaks or discharges is so great at hotspot sites that infiltration of stormwater or snowmelt is ***prohibited.***

Table 8.10. Potential Stormwater Hotspot and Site Design Responses

Potential Stormwater Hotspot Operation	SWPP Required?	Restricted Infiltration	No Infiltration
Facilities w/NPDES Industrial permits	Yes	■	■
Public works yard	Yes		✓
Ports, shipyards and repair facilities	Yes		✓
Railroads/ equipment storage	Yes		✓
Auto and metal recyclers/scrapyards	Yes		✓
Petroleum storage facilities	Yes		✓
Highway maintenance facilities	Yes		✓
Wastewater, solid waste and composting facilities	Yes		✓
Industrial machinery and equipment	Yes	✓	
Trucks and trailers	Yes	✓	
Airfields	Yes	✓	
Aircraft maintenance areas	Yes		✓
Fleet storage areas	Yes		✓
Parking lots (40 or more parking spaces)	No	✓	
Gas stations	No		✓
Highways (2500 ADT)	No	✓	
Construction business (paving, heavy equipment storage and maintenance	No	✓	
Retail/wholesale vehicle/ equipment dealers	No	✓	
Convenience stores/fast food restaurants	No	✓	
Vehicle maintenance facilities	No		✓
Car washes	No		✓
Nurseries and garden centers	No	✓	
Golf courses	No	✓	
Note: For a full list of potential stormwater hotspots. please consult Schueler et al (2004)			
Key: ■ = depends on facility; ✓ = criterion applies			

10.2. Other Environmental and Community Issues

The following is a list of several other community and environmental concerns that may also arise when infiltration practices are proposed:

Nuisance Conditions. Poorly designed infiltration practices can create potential nuisance problems such as basement flooding, poor yard drainage and standing water. In most cases, these problems can be minimized through proper adherence to the setback, soil testing and pre-treatment requirements outlined in this specification.

Mosquito Risk. Infiltration practices have some potential to create conditions favorable to mosquito breeding, if they clog and have standing water for extended periods.

Groundwater Injection Permits. Groundwater injection permits are required if the infiltration practice is deeper than the longest surface area dimension of the practice (EPA, 2008). Designers should investigate whether or not a proposed infiltration practice is subject to ~~a~~ state or local groundwater injection permit requirements.

SECTION 11: REFERENCES

Center for Watershed Protection (CWP). 2007. *Urban Stormwater Retrofit Practices*. Manual 3 in the Urban Subwatershed Restoration Manual Series. Ellicott City, MD.

Center for Watershed Protection (CWP). 2003. *New York State Stormwater Management Design Manual*. Prepared for the New York State Department of Environmental Conservation. Albany, NY.

Delaware Urban Runoff Management Approach. Available online at:
http://www.dnrec.state.de.us/DNREC2000/Divisions/Soil/Stormwater/New/GT_Stds%20&%20Specs_06-05.pdf

Maryland Department of Environment (MDE). 2000. *Maryland Stormwater Design Manual*. Baltimore, MD.

New Jersey Stormwater Best Management Practices Manual. Available online at:
http://www.nj.gov/dep/watershedmgt/bmpmanualfeb2004.htm

North Shore City. 2007. *Infiltration Design Guidelines*. Sinclair, Knight and Merz. Auckland, New Zealand

Pennsylvania. *Draft Stormwater Best Management Practices Manual*. Available online at:
http://www.dep.state.pa.us/dep/subject/advcoun/Stormwater/stormwatercomm.htm

Schueler, T., C. Swann, T. Wright and S. Sprinkle. 2004. *Pollution Source Control Practices*. Manual No. 8 in the Urban Subwatershed Restoration Manual Series. Center for Watershed Protection. Ellicott City, MD.

Virginia Stormwater Management Handbook. 1999. *Volumes 1 and 2*. Richmond, VA.

APPENDIX 8-A

INFILTRATION SOIL TESTING PROCEDURES

I. Test Pit/Boring Procedures

1. One (1) test pit or standard soil boring should be provided for every 1,000 square feet of the proposed infiltration area.

2. The location of each test pit or standard soil boring should correspond to the location of the proposed infiltration area.

3. Excavate each test pit or penetrate each standard soil boring to a depth at least 2 feet below the bottom of the proposed infiltration area.

4. If the groundwater table is located within 2 feet of the bottom of the proposed facility, determine the depth to the groundwater table immediately upon excavation and again 24 hours after excavation is completed.

5. Conduct Standard Penetration Testing (SPT) every 2 feet to a depth that is 2 feet below the bottom of the proposed infiltration area.

6. Determine the USDA or Unified Soil Classification system textures at the bottom of the proposed infiltration area and at a depth that is 2 feet below the bottom. All soil horizons should be classified and described.

7. If bedrock is located within 2 feet of the bottom of the proposed infiltration area, determine the depth to the bedrock layer.

8. Test pit/soil boring stakes should be left in the field to identify where soil investigations were performed.

II. Infiltration Testing Procedures

1. One infiltration test should be conducted for every 1,000 square feet of surface area for the infiltration area.

2. The location of each infiltration test should correspond to the location of the proposed infiltration area.

3. Install a test casing (e.g., a rigid, 4 to 6 inch diameter pipe) to a depth 2 feet below the bottom of the proposed infiltration area.

4. Remove all loose material from the sides of the test casing and any smeared soil material from the bottom of the test casing to provide a natural soil interface into which water may

percolate. If desired, a 2-inch layer of coarse sand or fine gravel may be placed at the bottom of the test casing to prevent clogging and scouring of the underlying soils. Fill the test casing with clean water to a depth of 2 feet, and allow the underlying soils to pre-soak for 24 hours.

5. After 24 hours, refill the test casing with another 2 feet of clean water and measure the drop in water level within the test casing after one hour. Repeat the procedure three (3) additional times by filling the test casing with clean water and measuring the drop in water level after one hour. A total of four (4) observations must be completed. The infiltration rate of the underlying soils may be reported either as the average of all four observations or the value of the last observation. The infiltration rate should be reported in terms of inches per hour.

6. Infiltration testing may be performed within an open test pit or a standard soil boring.

7. After infiltration testing is completed, the test casing should be removed and the test pit or soil boring should be backfilled and restored.

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 9

BIORETENTION

VERSION 1.9
March 1, 2011

SECTION 1: DESCRIPTION

Individual bioretention areas can serve highly impervious drainage areas less than two (2) acres in size. Surface runoff is directed into a shallow landscaped depression that incorporates many of the pollutant removal mechanisms that operate in forested ecosystems. The primary component of a bioretention practice is the filter bed, which has a mixture of sand, soil, and organic material as the filtering media with a surface mulch layer. During storms, runoff temporarily ponds 6 to 12 inches above the mulch layer and then rapidly filters through the bed. Normally, the filtered runoff is collected in an underdrain and returned to the storm drain system. The underdrain consists of a perforated pipe in a gravel layer installed along the bottom of the filter bed. A bioretention facility with an underdrain system is commonly referred to as a *Bioretention Filter*.

Bioretention can also be designed to infiltrate runoff into native soils. This can be done at sites with permeable soils, a low groundwater table, and a low risk of groundwater contamination. This design features the use of a “partial exfiltration” system that promotes greater groundwater recharge. Underdrains are only installed beneath a portion of the filter bed, above a stone “sump” layer, or eliminated altogether, thereby increasing stormwater infiltration. A bioretention facility without an underdrain system, or with a storage sump in the bottom is commonly referred to as a *Bioretention Basin*.

Small-scale or Micro-Bioretention used on an individual residential lot is commonly referred to as a *Rain Garden*.

SECTION 2: PERFORMANCE

Bioretention creates a good environment for runoff reduction, filtration, biological uptake, and microbial activity, and provides high pollutant removal. Bioretention can become an attractive landscaping feature with high amenity value and community acceptance. The overall stormwater functions of the bioretention are summarized in **Table 9.1**.

Table 9.1. Summary of Stormwater Functions Provided by Bioretention Basins

Stormwater Function	Level 1 Design	Level 2 Design
Annual Runoff Volume Reduction (RR)	40%	80%
Total Phosphorus (TP) EMC Reduction[1] by BMP Treatment Process	25%	50%
Total Phosphorus (TP) Mass Load Removal	55%	90%
Total Nitrogen (TN) EMC Reduction[1] by BMP Treatment Process	40%	60%
Total Nitrogen (TN) Mass Load Removal	64%	90%
Channel and Flood Protection	• Use the Runoff Reduction Method (RRM) Spreadsheet to calculate the Cover Number (CN) Adjustment ***OR*** • Design extra storage (optional; as needed) on the surface, in the engineered soil matrix, and in the stone/underdrain layer to accommodate a larger storm, and use NRCS TR-55 Runoff Equations[2] to compute the CN Adjustment.	

[1] Change in event mean concentration (EMC) through the practice. Actual nutrient mass load removed is the product of the removal rate and the runoff reduction rate(see Table 1 in the *Introduction to the New Virginia Stormwater Design Specifications*).
[2] NRCS TR-55 Runoff Equations 2-1 thru 2-5 and Figure 2-1 can be used to compute a curve number adjustment for larger storm events based on the retention storage provided by the practice(s).

Sources: CWP and CSN (2008) and CWP (2007)

SECTION 3: DESIGN TABLES

The most important design factor to consider when applying bioretention to development sites is the **scale** at which it will be applied, as follows:

Micro-Bioretnetion or Rain Gardens. These are small, distributed practices designed to treat runoff from small areas, such as individual rooftops, driveways and other on-lot features in single-family detatched residential developments. Inflow is typically sheet flow, or can be concentrated flow with energy dissipation, when located at downspouts.

Bioretention Basins. These are structures treating parking lots and/or commercial rooftops, usually in commercial or institutional areas. Inflow can be either sheetflow or concentrated flow. Bioretention basins may also be distributed throughout a residential subdivision, but ideally they should be located in common area or within drainage easements, to treat a combination of roadway and lot runoff.

Urban Bioretention. These are structures such as expanded tree pits, curb extensions, and foundation planters located in ultra-urban developed areas such as city streetscapes. Please refer to **Appendix 9-A** of this specification for design criteria for Urban Bioretention.

Figure 9.1. A typical Bioretention Filter treating a commercial rooftop

The major design goal for bioretention is to maximize runoff volume reduction and nutrient removal. To this end, designers may choose to go with the baseline design (Level 1) or choose an enhanced design (Level 2) that maximizes nutrient and runoff reduction. If soil conditions require an underdrain, bioretention areas can still qualify for the Level 2 design if they contain a stone storage layer beneath the invert of the underdrain.

Both stormwater quality and quantity credits are accounted for in the Runoff Reduction Method (RRM) spreadsheet. The water quality credit represents an annual load reduction as a combination of the annual reduction of runoff volume (40% and 80% from Level 1 and Level 2 designs, respectively) and the reduction in the pollutant event mean concentration (EMC) (25% and 50% from Level 1 & 2 designs, respectively).

To compute the water quantity reduction for larger storm events, the designer can similarly use the RRM spreadsheet or, as an option, the designer may choose to compute the adjusted curve number associated with the retention storage using the TR-55 Runoff Equations, as noted in **Table 9.1**. The adjusted curve number is then used to compute the peak discharge for the required design storms.

Tables 9.2 and 9.3 outline the Level 1 and 2 design guidelines for the two scales of bioretention design.

Table 9.2. Micro-Bioretention (Rain Garden) Design Criteria[1]

Level 1 Design (RR 40 TP: 25)	**Level 2 Design (RR: 80 TP: 50)**
Sizing: Filter surface area (sq. ft.) = 3% [2] of the contributing drainage area (CDA).	Sizing: Filter surface area (sq. ft.) = 4% [2] of the CDA (can be divided into different cells at downspouts).
Maximum contributing drainage area = 0.5 acres; 25% Impervious Cover (IC) [2]	
One cell design (can be divided into smaller cells at downspout locations) [2]	
Maximum Ponding Depth = 6 inches	
Filter Media Depth minimum = 18 inches; Recommended maximum = 36 inches	Filter Media Depth minimum = 24 inches; Recommended maximum = 36 inches
Media: mixed on-site or supplied by vendor	Media: supplied by vendor
All Designs: Media mix tested for an acceptable phosphorus index (P-Index) of between 10 and 30, ***OR*** Between 7 and 21 mg/kg of P in the soil media	
Sub-soil testing: not needed if an underdrain is used; Min infiltration rate > 1 inch/hour in order to remove the underdrain requirement.	Sub-soil testing: one per practice; Min infiltration rate > 1/2 inch/hour; Min infiltration rate > 1 inch/hour in order to remove the underdrain requirement.
Underdrain: corrugated HDPE or equivalent.	Underdrain: corrugated HDPE or equivalent, with a minimum 6-inch stone sump below the invert; ***OR*** none, if soil infiltration requirements are met
Clean-outs: not needed	
Inflow: sheetflow or roof leader	
Pretreatment: external (leaf screens, grass filter strip, energy dissipater, etc.).	Pretreatment: external *plus* a grass filter strip
Vegetation: turf, herbaceous, or shrubs (min = 1 out of those 3 choices).	Vegetation: turf, herbaceous, shrubs, or trees (min = 2 out of those 4 choices).
Building setbacks: 10 feet down-gradient; 25 feet up-gradient	
[1] Consult **Appendix 9-A** for design criteria for Urban Bioretention Practices. [2] Micro-Bioretention (Rain Gardens) can be located at individual downspout locations to treat up to 1,000 sq. ft. of impervious cover (100% IC); the surface area is sized as 5% of the roof area (Level 1) or 6% of the roof area (Level 2), with the remaining Level 1 and Level 2 design criteria as provided in **Table 9.2**. If the Rain Garden is located so as to capture multiple rooftops, driveways, and adjacent pervious areas, the sizing rules within **Table 9.2** should apply.	

Table 9.3. Bioretention Filter and Basin Design Criteria

Level 1 Design (RR 40 TP: 25)	Level 2 Design (RR: 80 TP: 50)
Sizing (**Section 6.1**): Surface Area (sq. ft.) = (T_v – the volume reduced by an upstream BMP) / Storage Depth [1]	Sizing (**Section 6.1**): Surface Area (sq. ft.) = [(1.25)(T_v) – the volume reduced by an upstream BMP] /Storage Depth [1]
Recommended maximum contributing drainage area = 2.5 acres	
Maximum Ponding Depth = 6 to 12 inches [2]	Maximum Ponding Depth = 6 to 12 inches [2]
Filter Media Depth minimum = 24 inches; recommended maximum = 6 feet	Filter Media Depth minimum = 36 inches; recommended maximum = 6 feet
Media & Surface Cover (**Section 6.6**) = supplied by vendor; tested for acceptable phosphorus index (P-Index) of between 10 and 30, ***OR*** Between 7 and 21 mg/kg of P in the soil media	
Sub-soil Testing (**Section 6.2**): not needed if an underdrain used; Min infiltration rate > 1/2 inch/hour in order to remove the underdrain requirement.	Sub-soil Testing (**Section 6.2**): one per 1,000 sq. ft. of filter surface; Min infiltration rate > 1/2 inch/hour in order to remove the underdrain requirement.
Underdrain (**Section 6.7**) = Schedule 40 PVC with clean-outs	Underdrain & Underground Storage Layer (**Section 6.7**) = Schedule 40 PVC with clean outs, and a minimum 12-inch stone sump below the invert; ***OR***, none, if soil infiltration requirements are met (**Section 6.2**)
Inflow: sheetflow, curb cuts, trench drains, concentrated flow, or the equivalent	
Geometry (**Section 6.3**): Length of shortest flow path/Overall length = 0.3; ***OR***, other design methods used to prevent short-circuiting; a one-cell design (not including the pre-treatment cell).	Geometry (**Section 6.3**): Length of shortest flow path/Overall length = 0.8; ***OR***, other design methods used to prevent short-circuiting; a two-cell design (not including the pretreatment cell).
Pre-treatment (**Section 6.4**): a pretreatment cell, grass filter strip, gravel diaphragm, gravel flow spreader, or another approved (manufactured) pre-treatment structure.	Pre-treatment (**Section 6.4**): a pretreatment cell *plus* one of the following: a grass filter strip, gravel diaphragm, gravel flow spreader, or another approved (manufactured) pre-treatment structure.
Conveyance & Overflow (**Section 6.5**)	Conveyance & Overflow (**Section 6.5**)
Planting Plan (**Section 6.8**): a planting template to include turf, herbaceous vegetation, shrubs, and/or trees to achieve surface area coverage of at least 75% within 2 years.	Planting Plan (**Section 6.8**): a planting template to include turf, herbaceous vegetation, shrubs, and/or trees to achieve surface area coverage of at least 90% within 2 years. If using turf, must combine with other types of vegetation [1].
Building Setbacks [3] (**Section 5**): 0 to 0.5 acre CDA = 10 feet if down-gradient from building or level (coastal plain); 50 feet if up-gradient. 0.5 to 2.5 acre CDA = 25 feet if down-gradient from building or level (coastal plain); 100 feet if up-gradient. (Refer to additional setback criteria in **Section 5**)	
Deeded Maintenance O&M Plan (**Section 8**)	
[1] Storage depth is the sum of the Void Ratio (V_r) of the soil media and gravel layers multiplied by their respective depths, plus the surface ponding depth. Refer to **Section 6.1**. [2] A ponding depth of 6 inches is preferred. Ponding depths greater than 6 inches will require a specific planting plan to ensure appropriate plant selection (**Section 6.8**). [3] These are recommendations for simple building foundations. If an in-ground basement or other special conditions exist, the design should be reviewed by a licensed engineer. Also, a special footing or drainage design may be used to justify a reduction of the setbacks noted above.	

SECTION 3: TYPICAL DETAILS

Figures 9.2 through 9.5 provide some typical details for several bioretention configurations. Also see additional details in **Appendix 9-B** of this design specification.

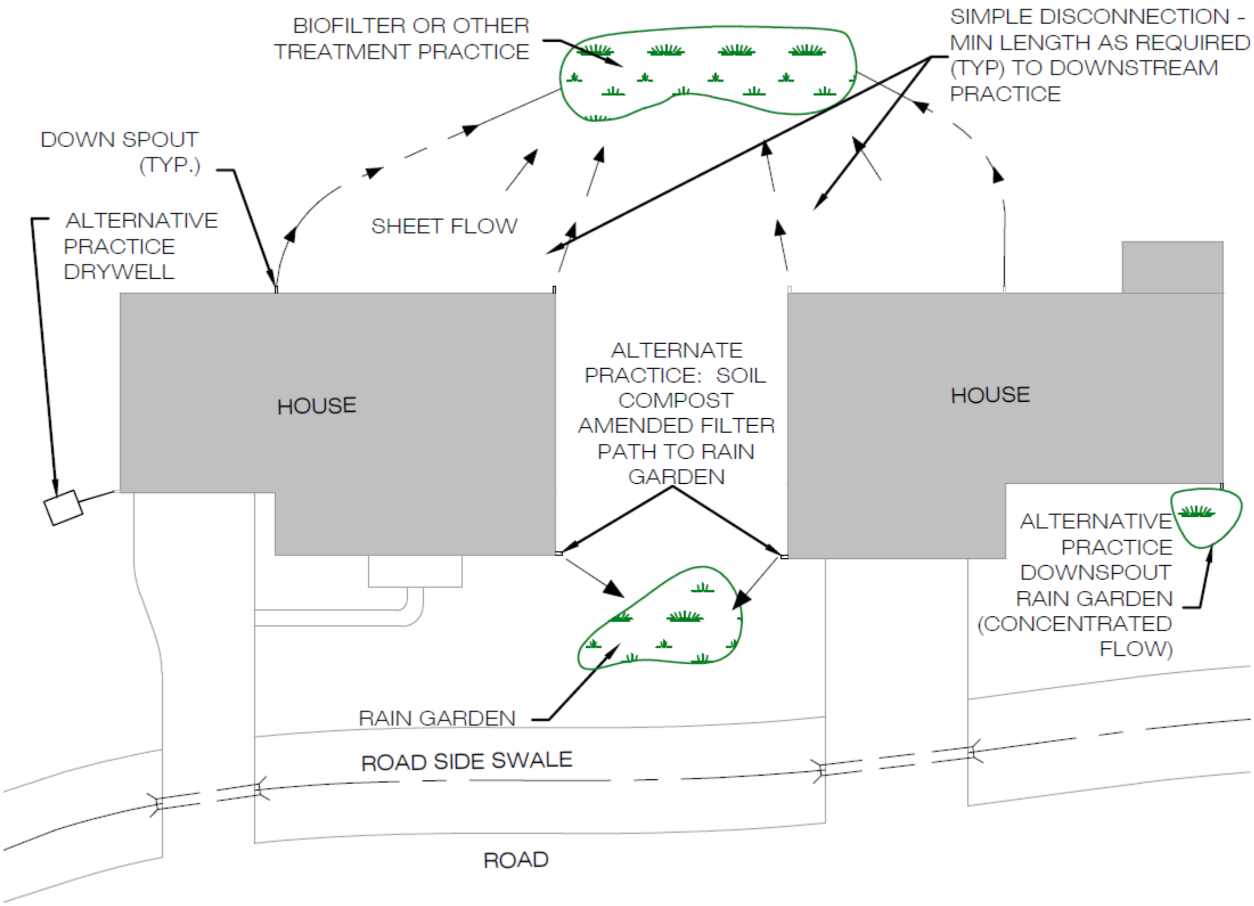


Figure 9.2. Residential Rooftop Treatment – Plan View: (a) Simple Disconnection to downstream Raingarden; (b) Disconnection – Alternative Practice: Raingarden; (c) Disconnection – Alternative Practice: Compost Amended Flow Path to downstream Raingarden

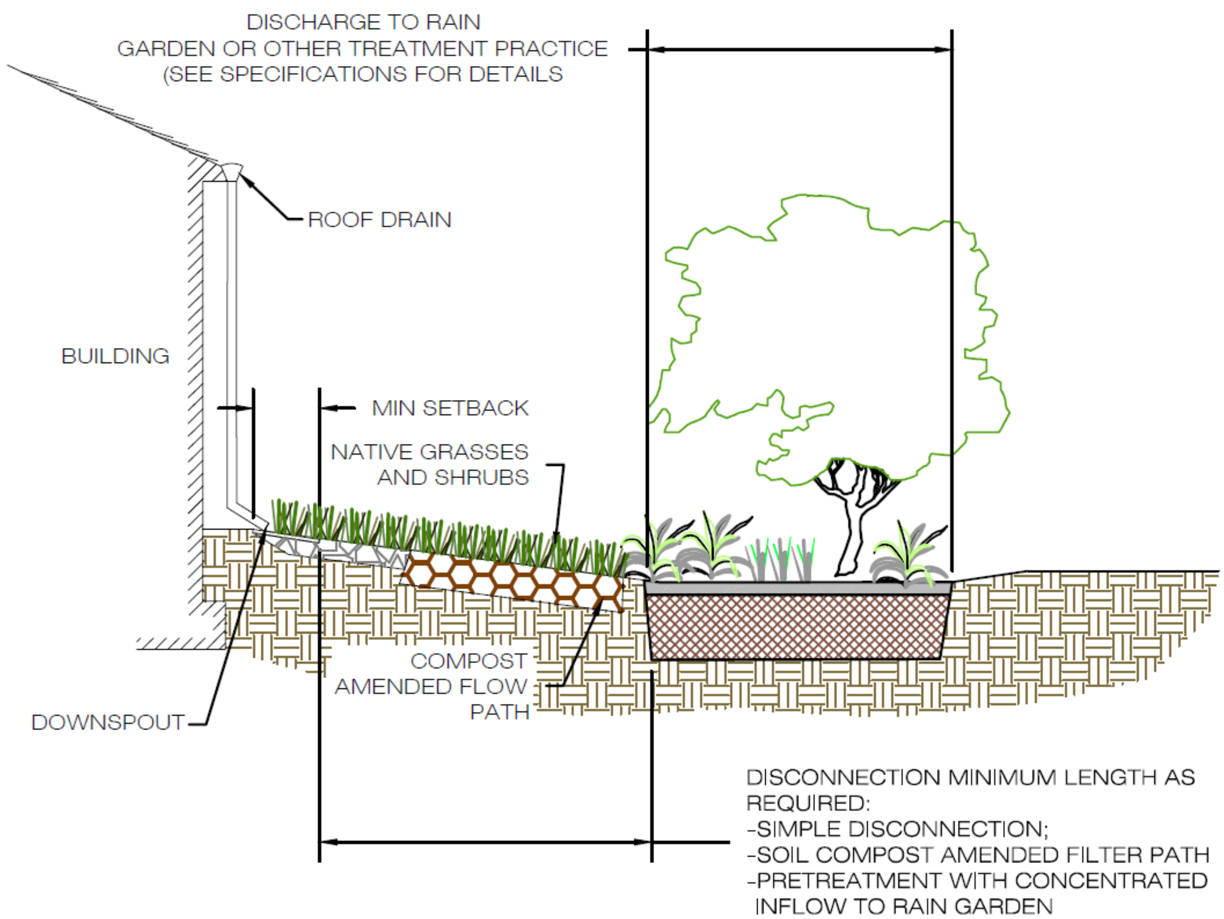


Figure 9.3A. Residential Rooftop Disconnection – Section View:
(a) Simple Disconnection to downstream Raingarden; (b) Disconnection – Alternative Practice: Compost Amended Flow Path to downstream Raingarden

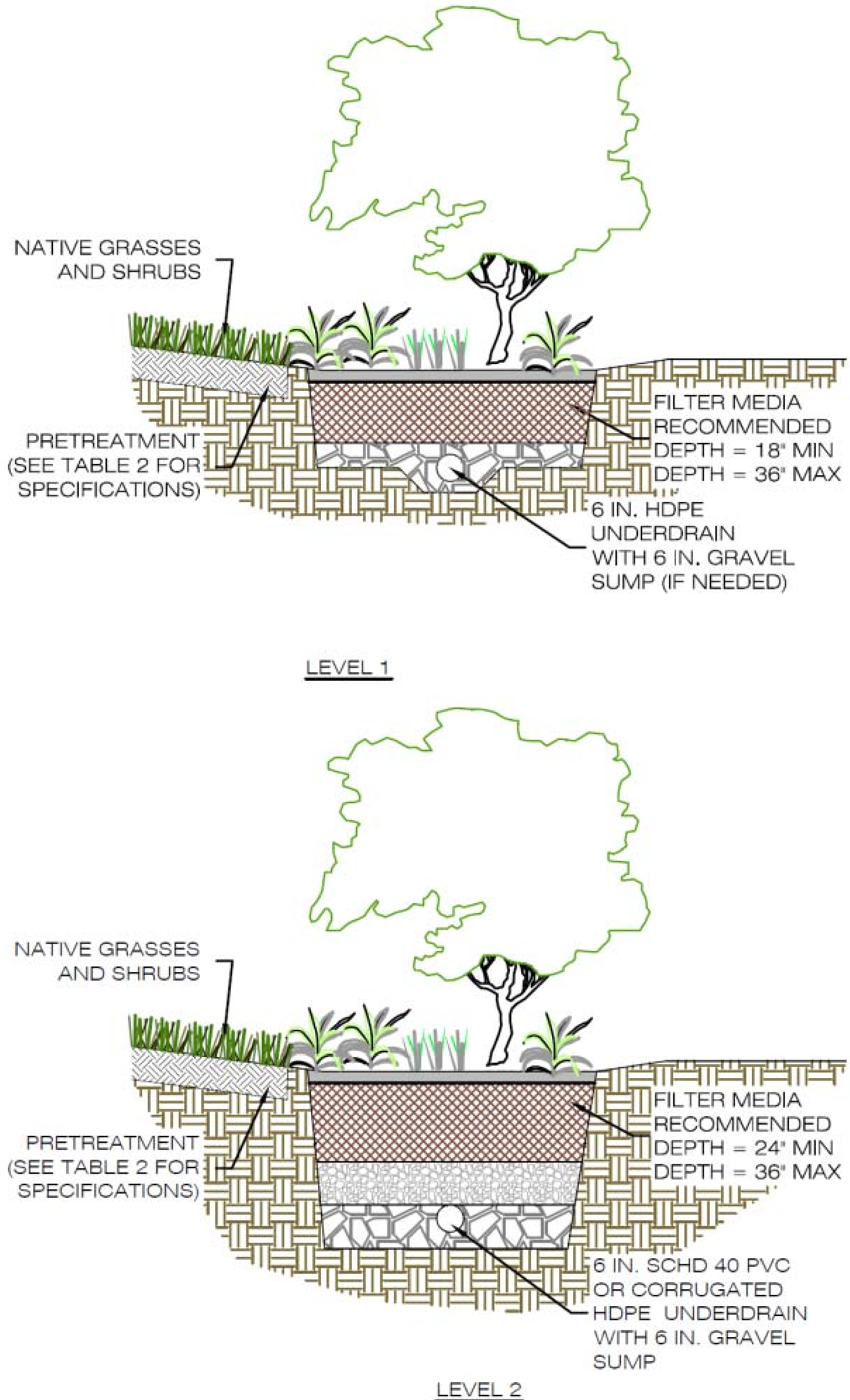


Figure 9.3B. Typical Micro-Bioretention Basin (Rain Garden) Level I and Level II – Section View:

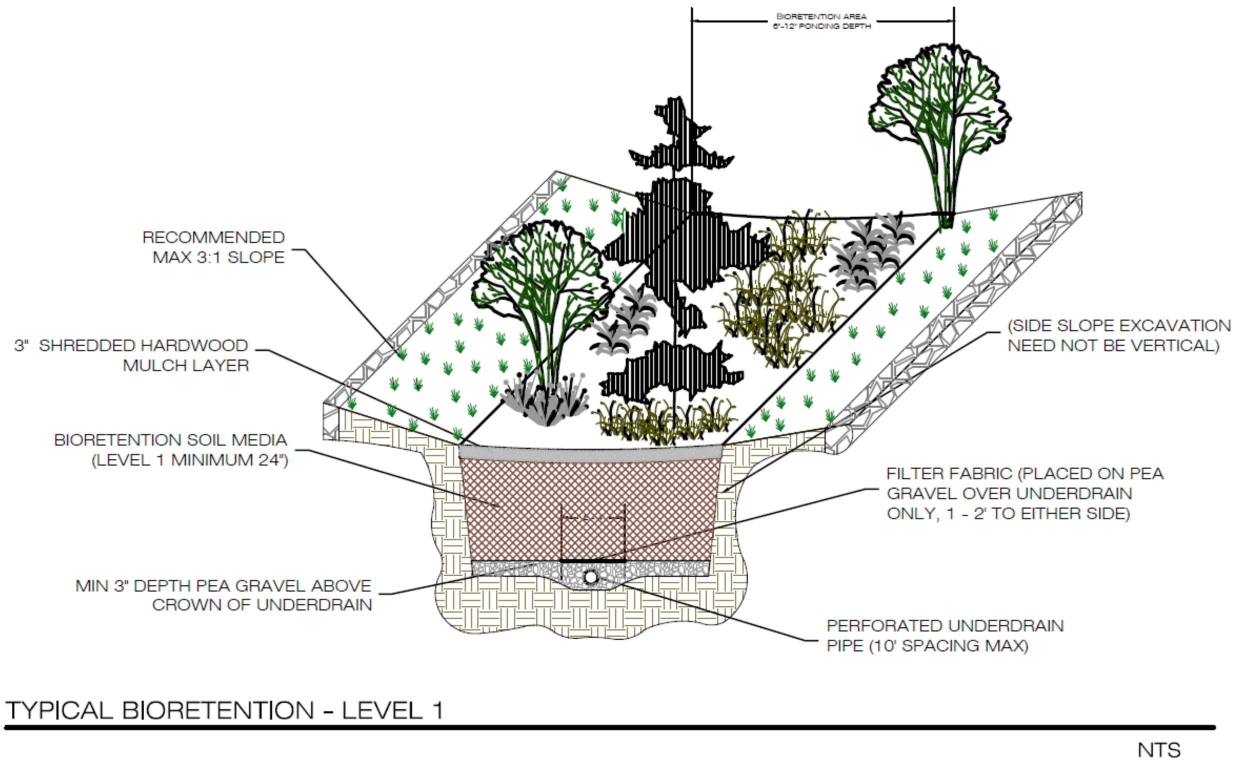


Figure 9.4a: Typical Detail of Bioretention Basin Level 1 Design

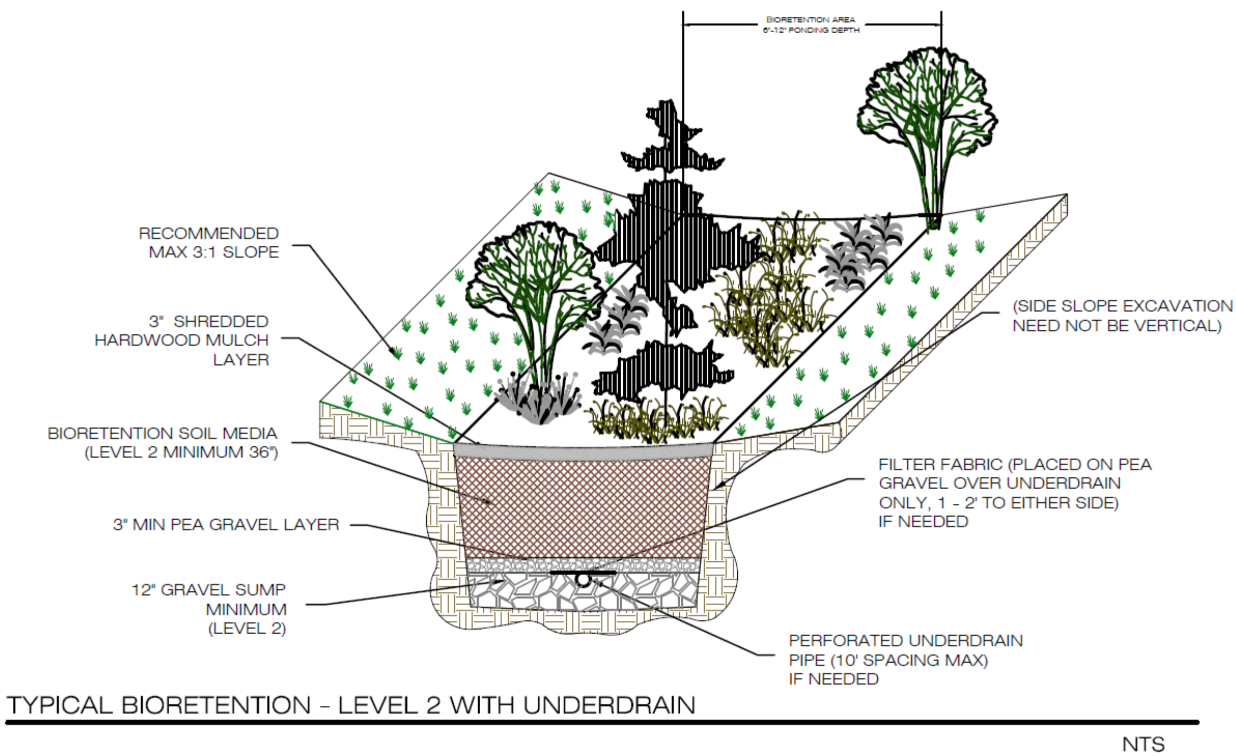


Figure 9.4b: Typical Detail of Bioretention Basin Level 2 Design

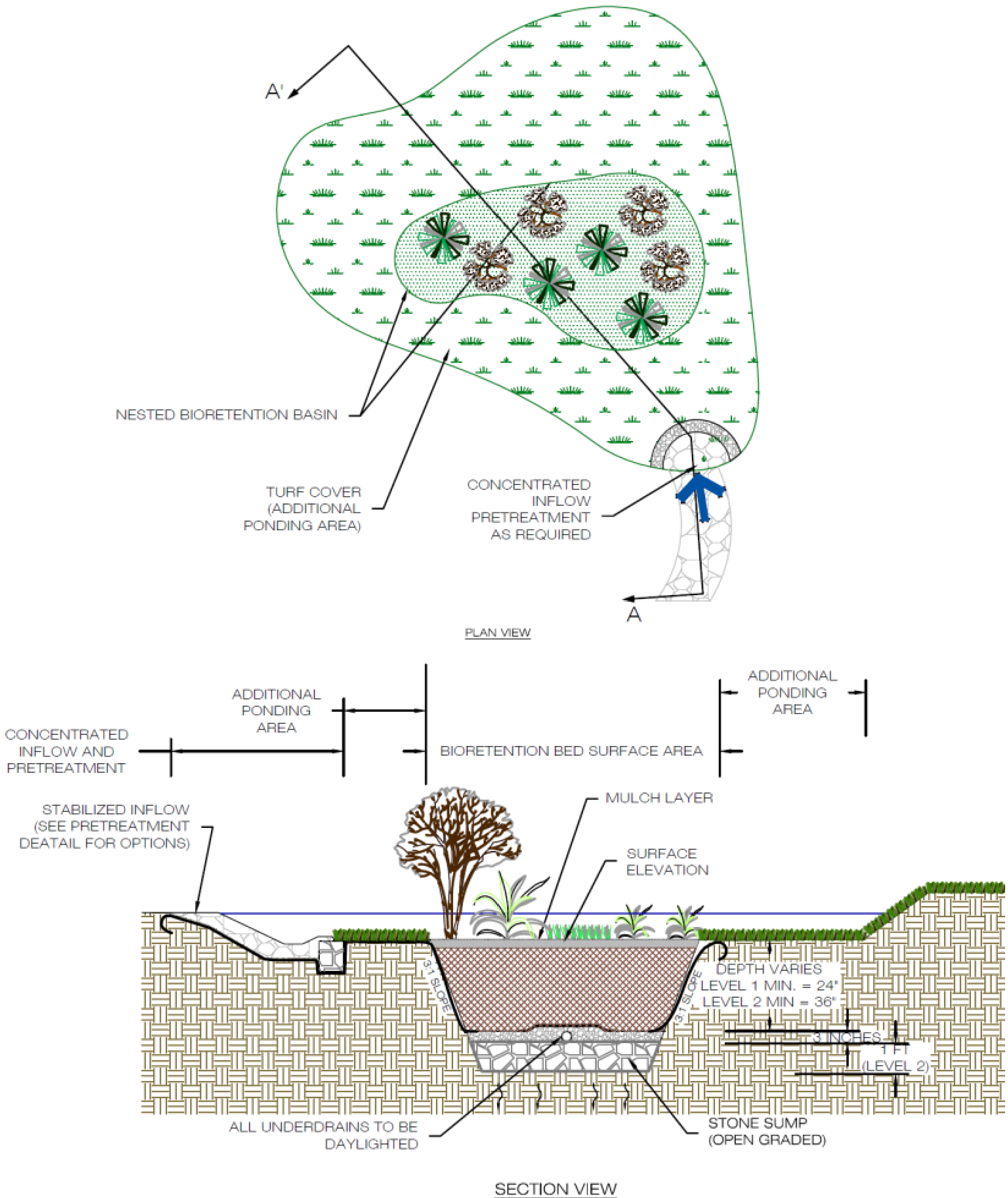


Figure 9.5. Typical Detail of Bioretention with Additional Surface Ponding

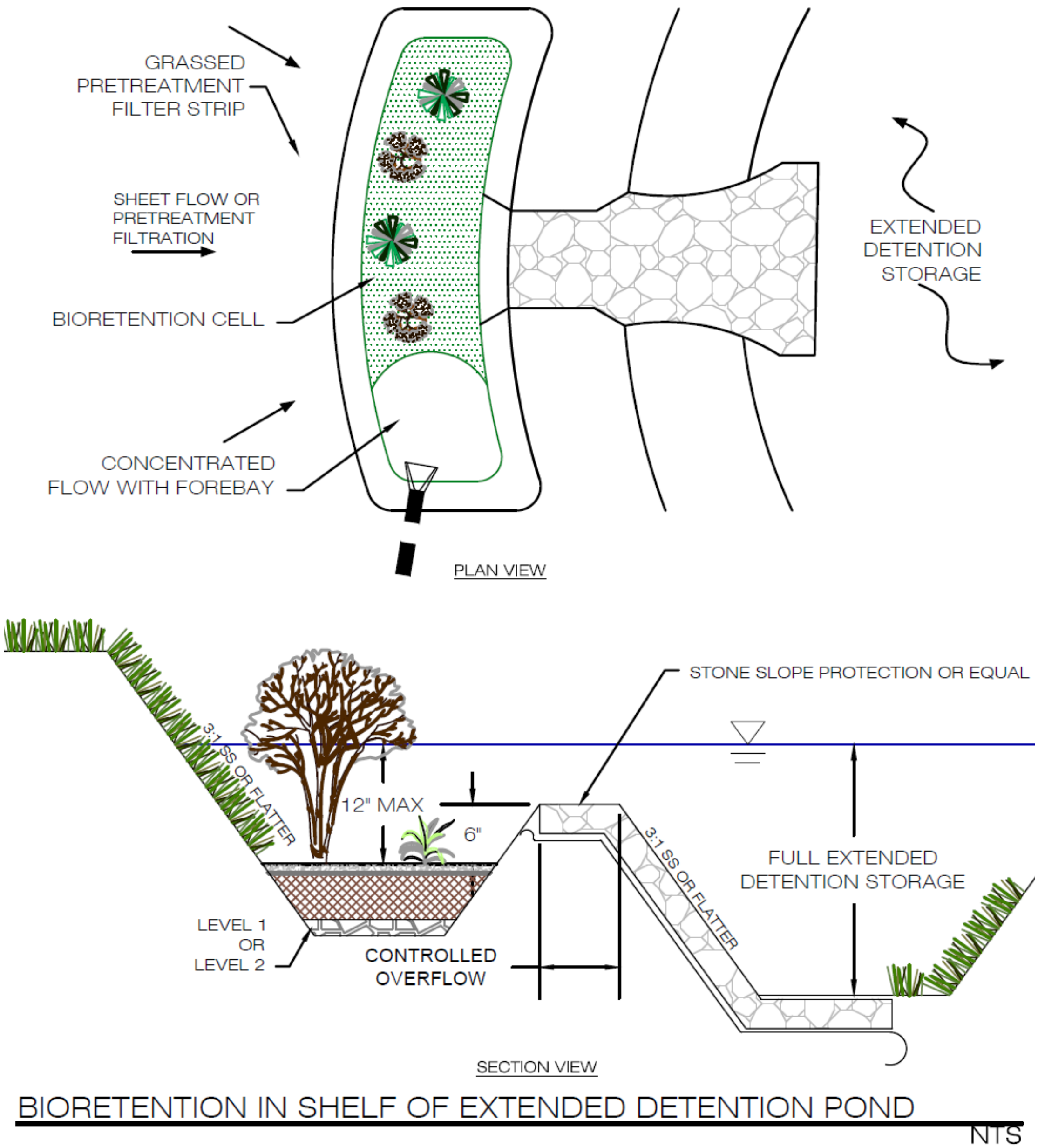
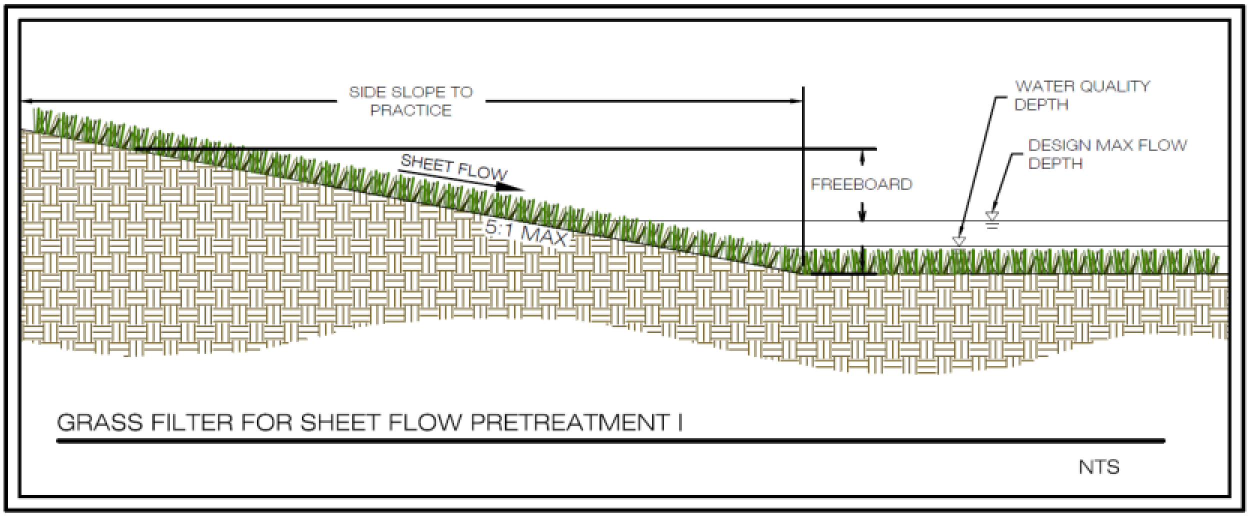


Figure 9.6. Typical Detail of a Bioretention Basin within the Upper Shelf of an ED Pond



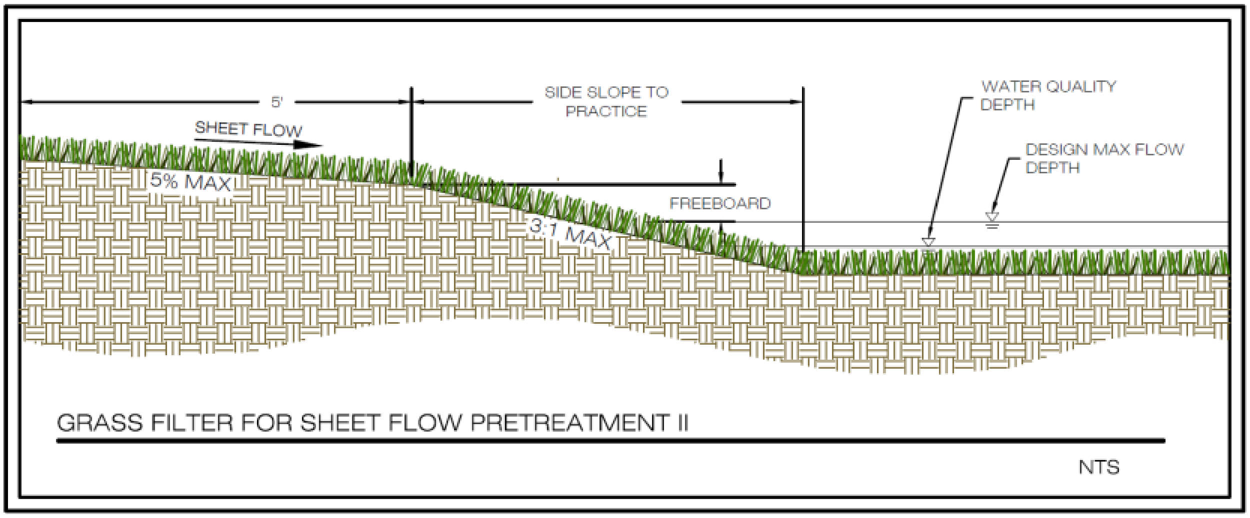


Figure 9.7 - Pretreatment I and II - Grass Filter for Sheet Flow

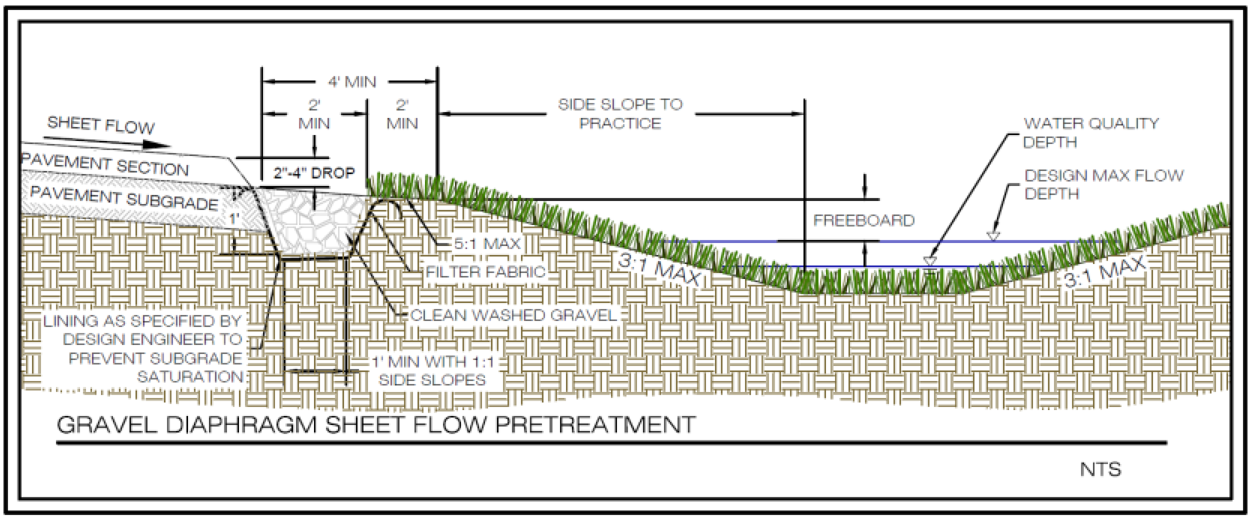


Figure 9.8 - Pretreatment – Gravel Diaphragm for Sheet Flow from Impervious or Pervious

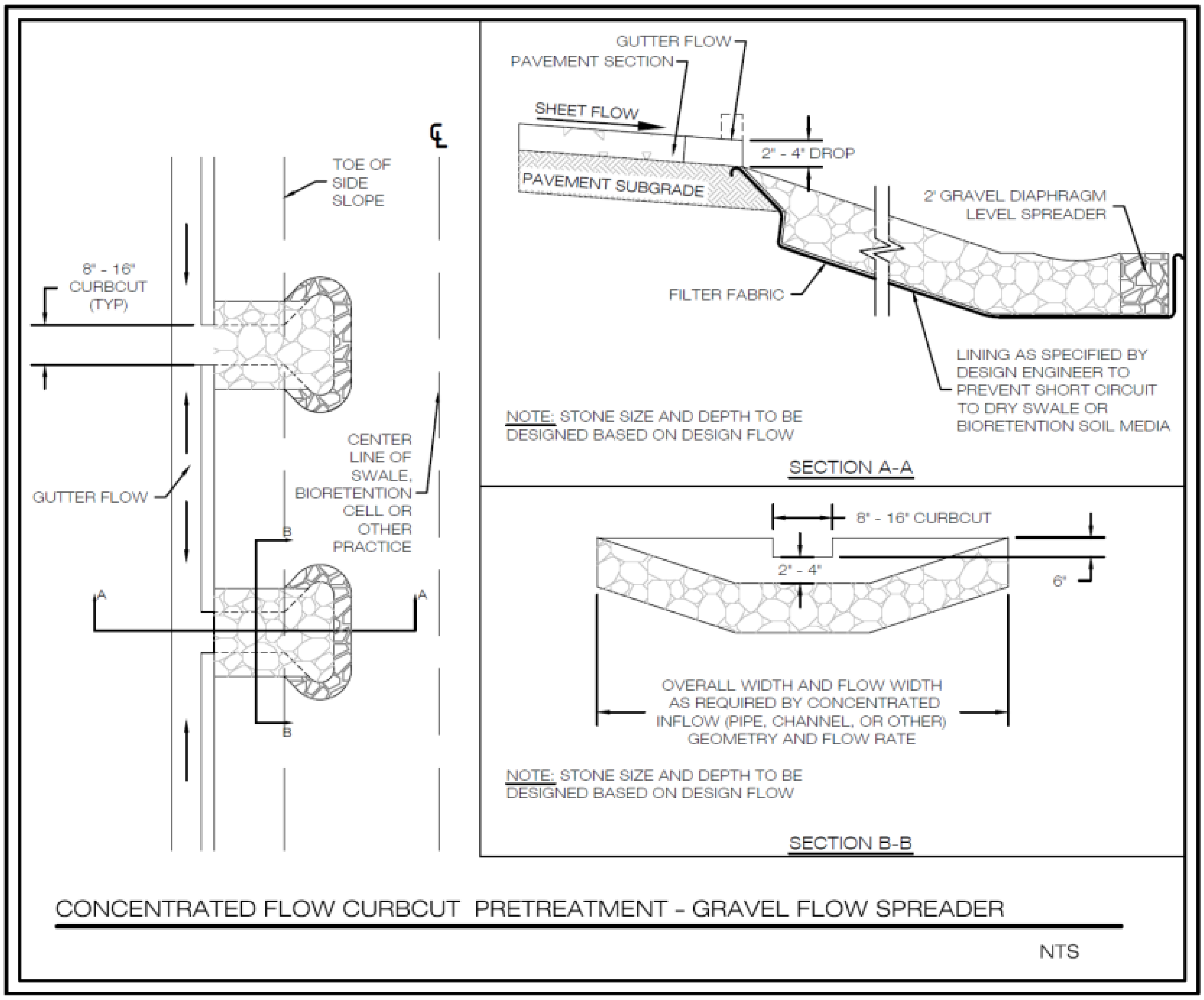


Figure 9.9: Pre-Treatment – Gravel Flow Spreader for Concentrated Flow

SECTION 5: PHYSICAL FEASIBILITY & DESIGN APPLICATIONS

5.1 Physical Feasibility

Bioretention can be applied in most soils or topography, since runoff simply percolates through an engineered soil bed and is returned to the stormwater system. Key constraints with bioretention include the following:

Available Space. Planners and designers can assess the feasibility of using bioretention facilities based on a simple relationship between the contributing drainage area and the corresponding required surface area. The bioretention surface area will be approximately 3% to 6% of the contributing drainage area, depending on the imperviousness of the CDA and the desired bioretention design level.

Site Topography. Bioretention is best applied when the grade of contributing slopes is greater than 1% and less than 5%.

Available Hydraulic Head. Bioretention is fundamentally constrained by the invert elevation of the existing conveyance system to which the practice discharges (i.e., the bottom elevation needed to tie the underdrain from the bioretention area into the storm drain system. In general, 4 to 5 feet of elevation above this invert is needed to create the hydraulic head needed to drive stormwater through a proposed bioretention filter bed. Less hydraulic head is needed if the underlying soils are permeable enough to dispense with the underdrain.

Water Table. Bioretention should always be separated from the water table to ensure that groundwater does not intersect the filter bed. Mixing can lead to possible groundwater contamination or failure of the bioretention facility. A separation distance of 2 feet is recommended between the bottom of the excavated bioretention area and the seasonally high ground water table. The separation distance may be reduced to 12 inches in coastal plain residential settings (Refer to **Section 7.2 –** Regional Adaptations).

Utilities. Designers should ensure that future tree canopy growth in the bioretention area will not interfere with existing overhead utility lines. Interference with underground utilities should also be avoided, particularly water and sewer lines. Local utility design guidance should be consulted in order to determine the horizontal and vertical clearance required between stormwater infrastructure and other dry and wet utility lines.

Soils. Soil conditions do not constrain the use of bioretention, although they determine whether an underdrain is needed. Impermeable soils in Hydrologic Soil Group (HSG) B, C or D usually require an underdrain, whereas HSG A soils generally do not. When designing a bioretention practice, designers should verify soil permeability by using the on-site soil investigation methods provided in Appendix 8-A of Stormwater Design Specification No. 8 (Infiltration).

Contributing Drainage Area. Bioretention cells work best with smaller contributing drainage areas, where it is easier to achieve flow distribution over the filter bed. Typical drainage area size can range from 0.1 to 2.5 acres and consist of up to 100% impervious cover. Three scales of bioretention are defined in this specification: (1) micro-bioretention or *Rain Gardens* (up to 0.5 acre contributing drainage area); (2) bioretention basins (up to 2.5 acres of contributing drainage area); and (3) Urban Bioretention (**Appendix 9-A**). Each of these has different design requirements (refer to **Tables 9.2 and 9.3** above). The maximum drainage area to a single bioretention basin or single cell of a bioretention basin is 5 acres, with a maximum recommended impervious cover of 2.5 acres (50% impervious cover) due to limitations on the ability of bioretention to effectively manage large volumes and peak rates of runoff. However, if hydraulic considerations are adequately addressed to manage the potentially large peak inflow of larger drainage areas (such as off-line or low-flow diversions, forebays, etc.), there may be case-by-case instances where the plan approving authority may allow these recommended maximums to be adjusted. In such cases, the bioretention facility should be located within the drainage area so as to capture the Treatment Volume (T_v) equally from the entire contributing area, and not fill the entire volume from the immediately adjacent area, thereby bypassing the runoff from the more remote portions of the site.

Hotspot Land Uses. Runoff from hotspot land uses should not be treated with infiltrating bioretention (i.e., constructed *without* an underdrain). For a list of potential stormwater hotspots, please consult Section 10.1 of Stormwater Design Specification No. 8 (Infiltration). An impermeable bottom liner and an underdrain system must be employed when bioretention is used to receive and treat hotspot runoff.

Floodplains. Bioretention areas should be constructed outside the limits of the ultimate 100-year floodplain.

No Irrigation or Baseflow. The planned bioretention area should not receive baseflow, irrigation water, chlorinated wash-water or other such non-stormwater flows that are not stormwater runoff.

Setbacks. To avoid the risk of seepage, do not allow bioretention areas to be hydraulically connected to structure foundations or pavement. Setbacks to structures and roads vary, based on the scale of the bioretention design (see **Table 9.2** above). At a minimum, bioretention basins should be located a horizontal distance of 100 feet from any water supply well (50 feet if the biofilter is lined), 50 feet from septic systems (20 feet if the biofilter is lined), and at least 5 feet from down-gradient wet utility lines. Dry utility lines such as gas, electric, cable and telephone may cross under bioretention areas if they are double-cased.

5.2 Potential Bioretention Applications

Bioretention can be used wherever water can be conveyed to a surface area. Bioretention has been used at commercial, institutional, and residential sites in spaces that are traditionally pervious and landscaped. It should be noted that special care must be taken to provide adequate pre-treatment for bioretention cells in space-constrained high traffic areas. Typical locations for bioretention include the following:

Parking lot islands. The parking lot grading is designed for sheet flow towards linear landscaping areas and parking islands between rows of spaces. Curb-less pavement edges can be used to convey water into a depressed island landscaping area. Curb cuts can also be used for this purpose, but they are more prone to blockage, clogging and erosion.

Parking lot edge. Small parking lots can be graded so that flows reach a curb-less pavement edge or curb cut before reaching catch basins or storm drain inlets. The turf at the edge of the parking lot functions as a filter strip to provide pre-treatment for the bioretention practice. The depression for bioretention is located in the pervious area adjacent to the parking lot.

Road medians, roundabouts, interchanges and cul-de-sacs. The road cross-section is designed to slope towards the center median or center island rather than the outer edge, using a curb-less edge.

Right-of-way or commercial setback. A linear configuration can be used to convey runoff in sheet flow from the roadway, or a grass channel or pipe may convey flows to the bioretention practice.

Courtyards. Runoff collected in a storm drain system or roof leaders can be directed to courtyards or other pervious areas on site where biorention can be installed.

Individual residential lots. Roof leaders can be directed to small bioretention areas, often called "rain gardens," located at the front, side, or rear of a home in a drainage easement. For smaller lots, the front yard bioretention corridor design may be preferable (See Stormwater Design Specification No. 1: Rooftop Disconnection).

Unused pervious areas on a site. Storm flows can be redirected from a a storm drain pipe to discharge into a bioretention area.

Dry Extended Detention (ED) basin. A bioretention cell can be located on an upper shelf of an extended detention basin, after the sediment forebay, in order to boost treatment. Depending on the ED basin design, the designer may choose to locate the bioretention cell in the bottom of the basin. However, the design must carefully account for the potentially deeper ponding depths (greater than 6 or 12 inches) associated with extended detention.

Retrofitting. Numerous options are available to retrofit bioretention in the urban landscape, as described in Profile Sheet ST-4 of Schueler et al (2007).

SECTION 6: DESIGN CRITERIA

6.1. Sizing of Bioretention Practices

6.1.1 Stormwater Quality

Sizing of the surface area (SA) for bioretention practices is based on the computed Treatment Volume (T_v) of the contributing drainage area and the storage provided in the facility. The required surface area (in square feet) is computed as the Treatment Volume (in cubic feet) divided by the equivalent storage depth (in feet). The equivalent storage depth is computed as the depth of media, gravel, or surface ponding (in feet) multiplied by the accepted void ratio.

The accepted Void Ratios (V_r) are (see **Figure 9.10** below):

Bioretention Soil Media $V_r = 0.25$
Gravel $V_r = 0.40$
Surface Storage $V_r = 1.0$

The equivalent storage depth for Level 1 with a 6-inch surface ponding depth and a 12-inch gravel layer is therefore computed as:

Equation 9.1. Bioretention Level 1 Design Storage Depth

$$(2 \text{ ft.} \times 0.25) + (1 \text{ ft.} \times 0.40) + (0.5 \times 1.0) = 1.40 \text{ ft.}$$

And the equivalent storage depth for Level 2 with a 6-inch surface ponding depth and a 12-inch gravel layer is computed as:

Equation 9.2. Bioretention Level 2 Design Storage Depth

$$(3\ ft.\ x\ 0.25) + (1\ ft.\ x\ 0.40) + (0.5\ x\ 1.0) = 1.65\ ft$$

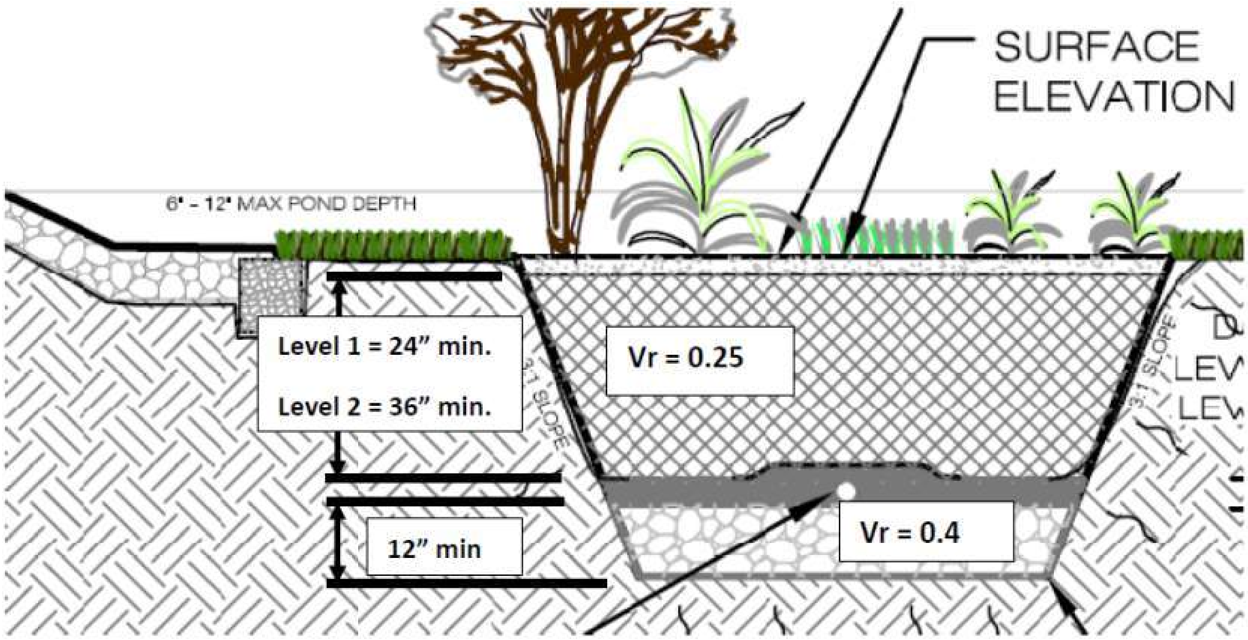


Figure 9.10. Typical Bioretention Section with Void Ratios for Volume Computations

Therefore, the Level 1 Bioretention Surface Area (SA) is computed as:

Equation 9.3. Bioretention Level 1 Design Surface Area

$$SA\ (sq.\ ft.) = \{T_v - \text{the volume reduced by an upstream BMP}\} / 1.40\ ft.$$

And the Level 2 Bioretention Surface Area is computed as:

Equation 9.4. Bioretention Level 2 Design Surface Area

$$SA\ (sq.\ ft.) = [(1.25 \ast Tv) - \text{the volume reduced by an upstream BMP}] / 1.65\ ft.$$

Where:

SA = Minimum surface area of bioretention filter (sq. ft.)

T_v = Treatment Volume (cu. ft.) = $[(1.0\ in.)(R_v)(A) / 12]$
(NOTE: R_v = the composite runoff coefficient from the RR Method)

Equations 9.1 through 9.4 should be modified if the storage depths of the soil media, gravel layer, or ponded water vary in the actual design or with the addition of any surface or subsurface storage components (e.g., additional area of surface ponding, subsurface storage chambers, etc.).

6.1.2 Stormwater Quantity

The water quality Treatment Volume (T_v) can be counted as part of the Channel Protection Volume or Overbank Flood Protection Volume to satisfy stormwater quantity control requirements. In addition, designers may be able to create additional surface storage by expanding the surface ponding footprint in order to accommodate a greater quantity credit for channel and/or flood protection, without necessarily increasing the soil media footprint. In other words, the engineered soil media would only underlay part of the surface area of the bioretention (see **Figure 9.10** above).

In this regard, the ponding footprint can be increased as follows to allow for additional storage:

- 50% surface area increase if the ponding depth is 6 inches or less.
- 25% surface area increase if the ponding depth is between 6 and 12 inches.

These values may be modified as additional data on the long term permeability of bioretention filters becomes available.

6.2. Soil Infiltration Rate Testing

In order to determine if an underdrain will be needed, one must measure the infiltration rate of subsoils at the invert elevation of the bioretention area, as noted in the soil testing requirements for each scale of bioretention, in Design **Tables 9.2 and 9.3** above. The infiltration rate of subsoils must exceed 1 inch per hour in order to dispense with the underdrain requirement for Rain Gardens, and 1/2 inch per hour for bioretention basins. On-site soil infiltration rate testing procedures are outlined in Appendix 8-A of the Stormwater Design Specification No. 8 (Infiltration). Soil testing is not needed for Level 1 bioretention areas, where an underdrain is used.

6.3. BMP Geometry

Bioretention basins must be designed with an internal flow path geometry such that the treatment mechanisms provided by the bioretention are not bypassed or short-circuited. Examples of short-circuiting include inlets or curb cuts that are very close to outlet structures (see **Figure 9.11** below), or incoming flow that is diverted immediately to the underdrain through stone layers. Short-circuiting can be particularly problematic when there are multiple curb cuts or inlets.

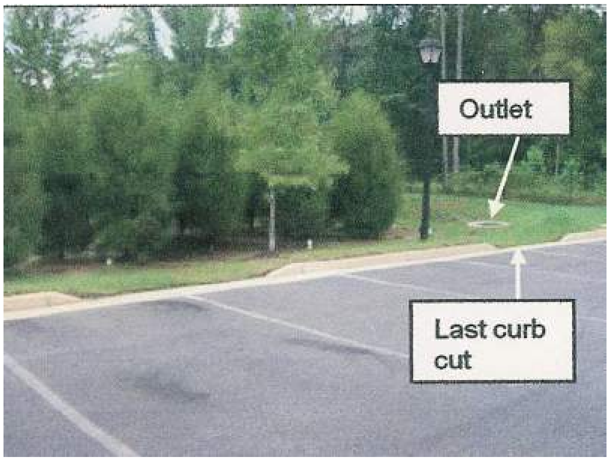


Figure 9.11. Examples of Short-Circuiting at Bioretention Facilities

In order for these bioretention areas to have an acceptable internal geometry, the “travel time” from each inlet to the outlet should be maximized, and incoming flow must be distributed as evenly as possible across the filter surface area.

One important characteristic is the length of the shortest flow path compared to the overall length, as shown in **Figure 9.12** below. In this figure, the ratio of the shortest flow path to the overall length is represented as:

Equation 9.5. Ratio of Shortest Flow Path to Overall Length

$$SFP / L$$

Where:

SFP = length of the shortest flow path

L = length from the most distant inlet to the outlet

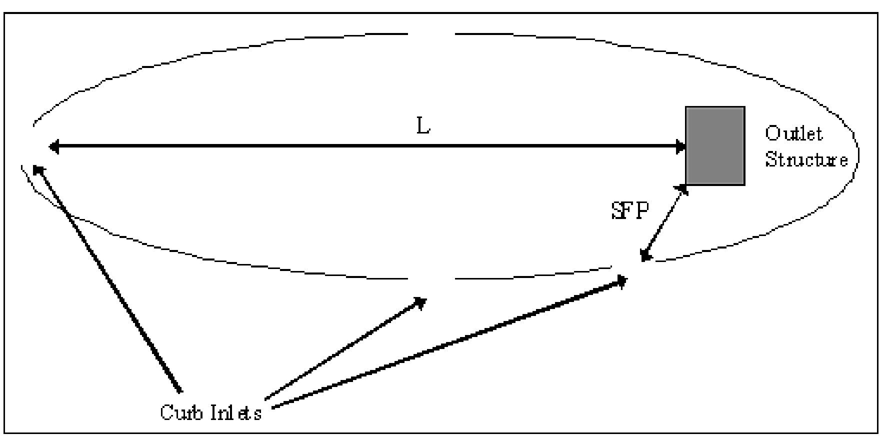


Figure 9.12. Diagram showing shortest flow path as part of BMP geometry

For Level 1 designs, the SFP/L ratio must be 0.3 or greater; the ratio must be 0.8 or greater for Level 2 designs. In some cases, due to site geometry, some inlets may not be able to meet these ratios. However, the drainage area served by such inlets should constitute no more than 20% of the contributing drainage area. Alternately, the designer may incorporate other design features that prevent short-circuiting, including features that help spread and distribute runoff as evenly as possible across the filter surface.

> ***Note: Local reviewers may waive or modify the guideline for the shortest flow path ratio in cases where (1) the outlet structure within the bioretention area is raised above the filter surface to the ponding depth elevation; and (2) the filter surface is flat.***

With regard to the first condition stated in the note above, field experience has shown that soil media immediately around a raised outlet structure is prone to scouring, erosion and, thus, short-circuiting of the treatment mechanism. For example, water can flow straight down through scour holes or sinkholes to the underdrain system (Hirschman et al., 2009). Design options should be used to prevent this type of scouring. One example is shown in **Figure 9.13**.

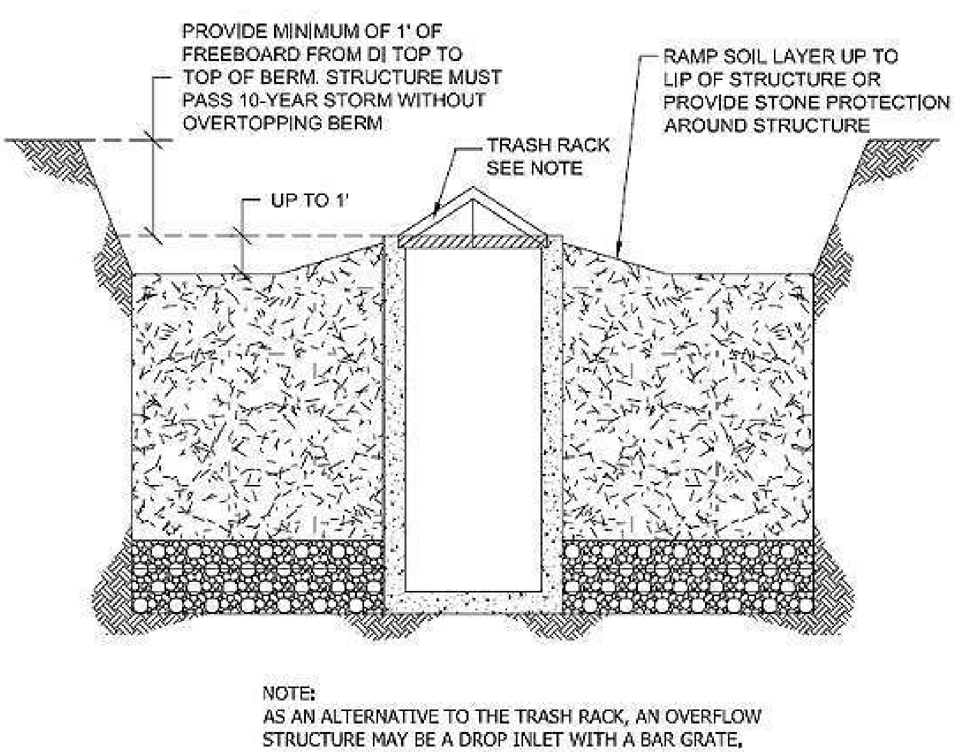


Figure 9.13. Typical Detail of how to prevent bypass or short-circuiting around the overflow structure

The designer should ensure that incoming flow is spread as evenly as possible across the filter surface to maximize the treatment potential.

6.4. Pre-treatment

Pre-treatment of runoff entering bioretention areas is necessary to trap coarse sediment particles before they reach and prematurely clog the filter bed. Pre-treatment measures must be designed to evenly spread runoff across the entire width of the bioretention area. Several pre-treatment measures are feasible, depending on the scale of the bioretention practice and whether it receives sheet flow, shallow concentrated flow or deeper concentrated flows. The following are appropriate pretreatment options:

For Micro Bioretention (Rain Gardens):

- **Leaf Screens** as part of the gutter system serve to keep the heavy loading of organic debris from accumulating in the bioretention cell.
- ***Grass Filter Strips*** (for sheet flow), applied on residential lots, where the lawn area can serve as a grass filter strip adjacent to a rain garden.
- ***Gravel or Stone Diaphragm*** (for either sheet flow or concentrated flow); this is a gravel diaphragm at the end of a downspout or other concentrated inflow point that should run perpendicular to the flow path to promote settling.

For Bioretention Basins:

- ***Pre-treatment Cells*** (channel flow): Similar to a forebay, this cell is located at piped inlets or curb cuts leading to the bioretention area and consists of an energy dissipater sized for the expected rates of discharge. It has a storage volume equivalent to at least 15% of the total Treatment Volume (inclusive) with a 2:1 length-to-width ratio. The cell may be formed by a wooden or stone check dam or an earthen or rock berm. Pretreatment cells do not need underlying engineered soil media, in contrast to the main bioretention cell.
- ***Grass Filter Strips*** (for sheet flow): Grass filter strips extend from the edge of pavement to the bottom of the bioretention basin at a 5:1 slope or flatter. Alternatively, provide a combined 5 feet of grass filter strip at a maximum 5% (20:1) slope and 3:1 or flatter side slopes on the bioretention basin. (**See Figure 9.7**)
- ***Gravel or Stone Diaphragms*** (sheet flow). A gravel diaphragm located at the edge of the pavement should be oriented perpendicular to the flow path to pre-treat lateral runoff, with a 2 to 4 inch drop. The stone must be sized according to the expected rate of discharge. (**See Figure 9.8**)
- ***Gravel or Stone Flow Spreaders*** (concentrated flow). The gravel flow spreader is located at curb cuts, downspouts, or other concentrated inflow points, and should have a 2 to 4 inch elevation drop from a hard-edged surface into a gravel or stone diaphragm. The gravel should extend the entire width of the opening and create a level stone weir at the bottom or treatment elevation of the basin. (**See Figure 9.9**)
- ***Innovative or Proprietary Structure*:** An approved proprietary structure with demonstrated capability of reducing sediment and hydrocarbons may be used to provide pre-treatment. Refer to the Virginia BMP Clearinghouse web site (http://www.vwrrc.vt.edu/swc/) for information on approved proprietary structures.

6.5. Conveyance and Overflow

For On-line bioretention: An overflow structure should always be incorporated into on-line designs to safely convey larger storms through the bioretention area. The following criteria apply to overflow structures:

- The overflow associated with the 2 and 10 year design storms should be controlled so that velocities are non-erosive at the outlet point (i.e., to prevent downstream erosion).
- Common overflow systems within bioretention practices consist of an inlet structure, where the top of the structure is placed at the maximum water surface elevation of the bioretention area, which is typically 6 to 12 inches above the surface of the filter bed (6 inches is the preferred ponding depth).
- The overflow capture device (typically a yard inlet) should be scaled to the application – this may be a landscape grate inlet or a commercial-type structure.
- The filter bed surface should generally be flat so the bioretention area fills up like a bathtub.

Off-line bioretention: Off-line designs are preferred (see **Figure 9.14** for an example). One common approach is to create an alternate flow path at the inflow point into the structure such that when the maximum ponding depth is reached, the incoming flow is diverted past the facility. In this case, the higher flows do not pass over the filter bed and through the facility, and additional flow is able to enter as the ponding water filtrates through the soil media.

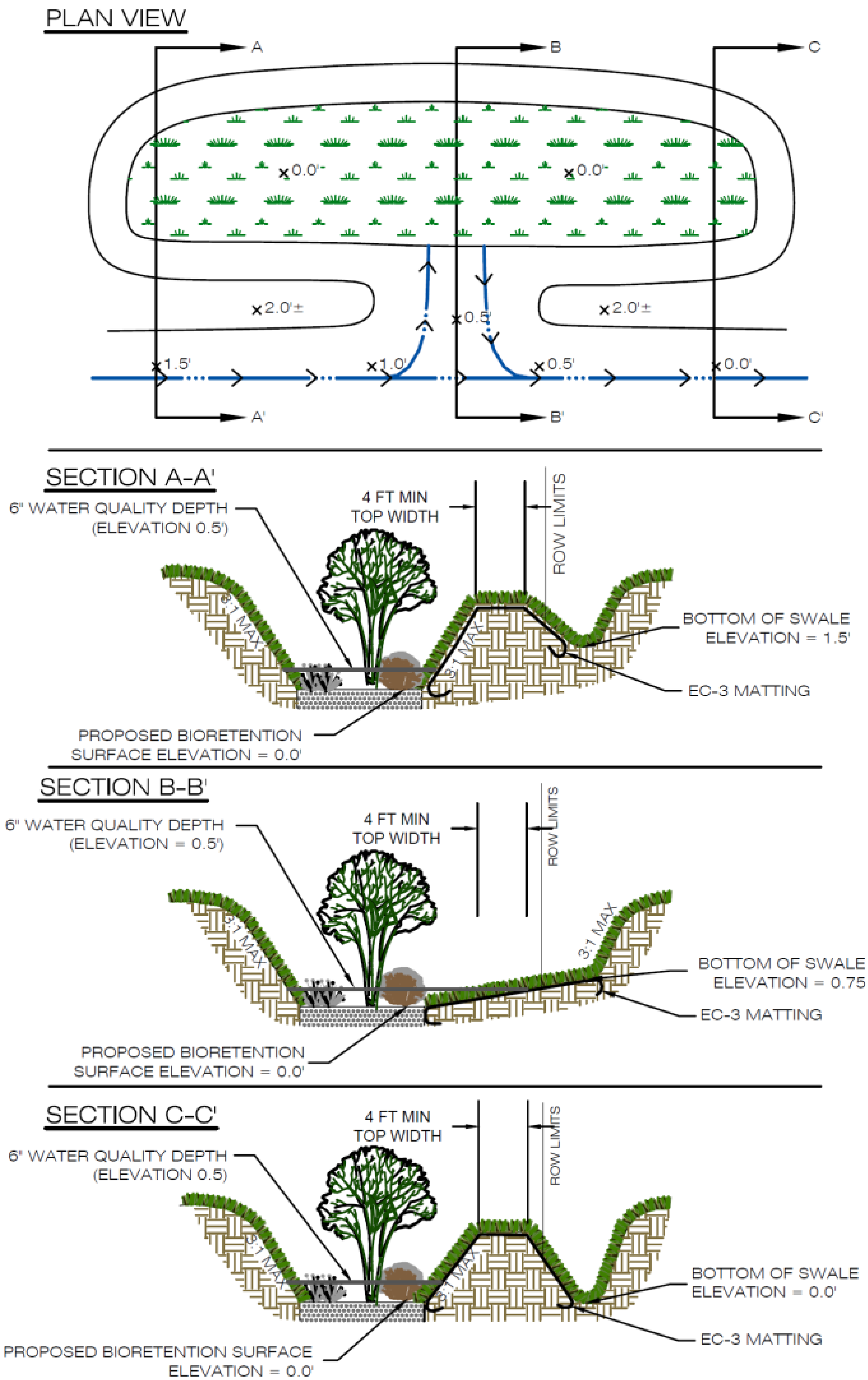


Figure 9.14. Typical Details for Off-Line Biofiltrattion

Another option is to utilize a low-flow diversion or flow splitter at the inlet to allow only the Treatment Volume to enter the facility. This may be achieved with a weir or curb opening sized for the target flow, in combination with a bypass channel. Using a weir or curb opening helps minimize clogging and reduces the maintenance frequency. (Further guidance on determining the Treatment Volume design peak flow rate will be necessary in order to ensure proper design of the diversion structure.)

6.6. Filter Media and Surface Cover

The filter media and surface cover are the two most important elements of a bioretention facility in terms of long-term performance. The following are key factors to consider in determining an acceptable soil media mixture.

- ***General Filter Media Composition.*** The recommended bioretention soil mixture is generally classified as a loamy sand on the USDA Texture Triangle, with the following composition:
  - 85% to 88% sand;
  - 8% to 12% soil fines; and
  - 3% to 5% organic matter.

It may be advisable to start with an open-graded coarse sand material and proportionately mix in topsoil that will likely contain anywhere from 30% to 50% soil fines (sandy loam, loamy sand) to achieve the desired ratio of sand and fines. An additional 3% to 5% organic matter can then be added. (The exact composition of organic matter and topsoil material will vary, making particle size distribution and recipe for the total soil media mixture difficult to define in advance of evaluating the available material.)

- ***P-Index.*** The P-Index provides a measure of soil phosphorus content and the risk of that phosphorus moving through the soil media. The risk of phosphorus movement through a soil is influenced by several soil physical properties: texture, structure, total pore space, pore-size, pore distribution, and organic matter. A soil with a lot of fines will hold phosphorus while also limiting the movement of water. A soil that is sandy will have a high permeability, and will therefore be less likely to hold phosphorus within the soil matrix.

  A primary factor in interpreting the desired P-Index of a soil is the bulk density. Saxton et. al. (1986) estimated generalized bulk densities and soil-water characteristics from soil texture. The expected bulk density of the loamy sand soil composition described above should be in the range of 1.6 to 1.7 g/cu. cm. Therefore, ***the recommended range for bioretention soil P-index of between 10 and 30*** corresponds to a ***phosphorus content range (mg of P to kg of soil) within the soil media of 7 mg/kg to 23 mg/kg***.

- ***Cation Exchange Capacity (CEC).*** The CEC of a soil refers to the total amount of positively charged elements that a soil can hold; it is expressed in milliequivalents per 100 grams (meq/100g) of soil. For agricultural purposes, these elements are the basic cations of calcium (Ca^{+2}), magnesium (Mg^{+2}), potassium (K^{+1}) and sodium (Na^{+1}) and the acidic cations of hydrogen (H^{+1}) and aluminum (Al^{+3}). The CEC of the soil is determined in part by the amount of clay and/or humus or organic matter present. ***Soils with CECs exceeding 10 are***

preferred for pollutant removal. Increasing the organic matter content of any soil will help to increase the CEC, since it also holds cations like the clays.

- ***Infiltration Rate.*** The bioretention soil media should have a minimum infiltration rate of 1 to 2 inches per hour (a proper soil mix will have an initial infiltration rate that is significantly higher).

- ***Depth.*** The standard minimum filter bed depth ranges from 24 and 36 inches for Level 1 and Level 2 designs, respectively, (18 to 24 inches for rain gardens or micro-bioretention). If trees are included in the bioretention planting plan, tree planting holes in the filter bed must be at least 4 feet deep to provide enough soil volume for the root structure of mature trees. Use turf, perennials or shrubs instead of trees to landscape shallower filter beds.

- ***Filter Media for Tree Planting Areas.*** A more organic filter media is recommended within the planting holes for trees, with a ratio of 50% sand, 30% toposoil and 20% acceptable leaf compost.

- ***Mulch.*** A 2 to 3 inch layer of mulch on the surface of the filter bed enhances plant survival, suppresses weed growth, and pre-treats runoff before it reaches the filter media. Shredded, aged hardwood bark mulch makes a very good surface cover, as it retains a significant amount of nitrogen and typically will not float away.

- ***Alternative to Mulch Cover.*** In some situations, designers may consider alternative surface covers such as turf, native groundcover, erosion control matting (coir or jute matting), river stone, or pea gravel. The decision regarding the type of surface cover to use should be based on function, cost and maintenance. Stone or gravel are not recommended in parking lot applications, since they increase soil temperature and have low water holding capacity.

- ***Media for Turf Cover.*** One adaptation is to design the filter media primarily as a sand filter with organic content only at the top. Leaf compost tilled into the top layers will provide organic content for the vegetative cover. If grass is the only vegetation, the ratio of compost may be reduced.

6.7. Underdrain and Underground Storage Layer

Some Level 2 designs will not use an underdrain (where soil infiltration rates meet minimum standards; see **Section 6.2** and **Section 3** design tables). For Level 2 designs with an underdrain, an underground storage layer of at 12 inches should be incorporated below the invert of the underdrain. The depth of the storage layer will depend on the target treatment and storage volumes needed to meet water quality, channel protection, and/or flood protection criteria. However, the bottom of the storage layer must be at least 2 feet above the seasonally high water table. The storage layer should consist of clean, washed #57 stone or an approved infiltration module.

All bioretention basins should include observation wells. The observation wells should be tied into any T's or Y's in the underdrain system, and should extend upwards to be flush with the surface, with a vented cap. In addition, cleanout pipes should be provided if the contributing drainage area exceeds 1 acre.

6.8. Bioretention Planting Plans

A landscaping plan must be provided for each bioretention area. Minimum plan elements shall include the proposed bioretention template to be used, delineation of planting areas, the planting plan, including the size, the list of planting stock, sources of plant species, and the planting sequence, including post-nursery care and initial maintenance requirements. It is highly recommended that the planting plan be prepared by a qualified landscape architect, in order to tailor the planting plan to the site-specific conditions.

Native plant species are preferred over non-native species, but some ornamental species may be used for landscaping effect if they are not aggressive or invasive. Some popular native species that work well in bioretention areas and are commercially available can be found in **Table 9.4**. Internet links to more detailed bioretention plant lists developed in piedmont and coastal plain communities of the Chesapeake Bay region are provided in **Table 9.5**.

The planting template refers to the form and combination of native trees, shrubs, and perennial ground covers that maintain the appearance and function of the bioretention area. The six most common bioretention templates are as follows:

- ***Turf.*** This option is typically restricted to on-lot micro-bioretention applications, such as a front yard rain garden. Grass species should be selected that have dense cover, are relatively slow growing, and require the least mowing and chemical inputs (e.g., fine fescue, tall fescue).

- ***Perennial garden.*** This option uses herbaceous plants and native grasses to create a garden effect with seasonal cover. It may be employed in both micro-scale and small scale bioretention applications. This option is attractive, but it requires more maintenance in the form of weeding.

- ***Perennial garden with shrubs.*** This option provides greater vertical form by mixing native shrubs and perennials together in the bioretention area. This option is frequently used when the filter bed is too shallow to support tree roots. Shrubs should have a minimum height of 30 inches.

- ***Tree, shrub and herbaceous plants.*** This is the traditional landscaping option for bioretention. It produces the most natural effect, and it is highly recommended for bioretention basin applications. The landscape goal is to simulate the structure and function of a native forest plant community.

- ***Turf and tree.*** This option is a lower maintenance version of the tree-shrub-herbaceous option 4, where the mulch layer is replaced by turf cover. Trees are planted within larger mulched islands to prevent damage during mowing operations.

- ***Herbaceous meadow.*** This is another lower maintenance approach that focuses on the herbaceous layer and may resemble a wildflower meadow or roadside vegetated area (e.g., with Joe Pye Weed, New York Ironweed, sedges, grasses, etc.). The goal is to establish a more natural look that may be appropriate if the facility is located in a lower maintenance area (e.g., further from buildings and parking lots). Shrubs and trees may be incorporated around the perimeter. Erosion control matting can be used in lieu of the conventional mulch layer.

Table 9.4. Popular Native Plant Materials for Bioretention

Perennials/Herbaceous	Shrubs	Trees
Virginia Wild Rye *(Elymus virginicus)*	Common Winterberry *(Ilex verticillatta)*	River Birch *(Betula nigra*)
Redtop Grass *(Agrostis alba)*	Inkberry *(Ilex glabra)*	Red Maple *(Acer rubrum)*
Swamp Milkweed *(Asclepias incarnata)*	Sweet Pepperbush *(Clethra ainifolia)*	Pin Oak *(Quercus palustris)*
Switchgrass *(Panicum virgatum)*	Wax Myrtle *(Myrica cerifera)*	Willow Oak *(Quercus phellos)*
Cardinal Flower *(Lobelia cardinalis)*	Virginia Sweetspire *(Itea virginica)*	Sweetgum *(Liquidambar styraciflua)*
Common Three Square *(Scirpus americanus)*	Swamp Azeala *(Azeala viscosum)*	Black Willow *(Salix nigra)*
Sensitive Fern *(Onoclea sensibilis)*	Button Bush *(Cephalanthus occidentalis)*	Grey Birch *(Betula populifolia)*
Blue Flag *(Iris versicolor)*	Black Haw *(Virburnum prunifolium))*	Black Gum *(Nyassa sylvatica)*
Woolgrass *(Scirpus cyperninus)*	Indigo Bush *(Amorpha fruticosa)*	Sycamore *(Platanus occidentalis)*
Indian Grass *(Sorghastrum nutans)*	Arrowwood *(Virburum dentatum)*	Green Ash *(Fraxinus pennsylvanica*
Marsh Marigold *(Caltha palustris)*		Sweetbay Magnolia* *(Magnolia virginiana)*
Joe Pye Weed *(Eupatorium purpureum)*		Atlantic White Cedar* *(Charnaecyparis thyoides)*
Turk's cap lily (*Lilium superbum*)		Bald Cypress* *(Taxodium distichum)*
Bee Balm *(Mornarda didyma)*		Grey Dogwood *(Cornus racernosa)*
Northern Sea Oats *(Chasmanthium latifolium)*		Smooth Alder *(Alnus serrulata))*
		Serviceberry *(Amelanchier canadensis)*
		Redbud (*Cercis candensis*)
		Box Elder *(Acer negundo)*
		Fringe Tree (*Chionanthus virginicus*)
Note: Prior to selection, please consult bioretention plant lists for more detailed information regarding inundation, drought and salt tolerance for each species. * most applicable to the coastal plain		

Table 9.5. Sources of Bioretention Plant Lists

Fairfax County, VA https://166.94.9.135/dpwes/publications/lti/07-03attach3.pdf
Prince Georges County, MD http://www.co.pg.md.us/Government/AgencyIndex/DER/ESD/Bioretention/pdf/Plant_list.pdf
City of Suffolk, VA http://www.suffolk.va.us/citygovt/udo/apdx_c/appendix_c9-2_plant_list.pdf
Virginia http://www.ext.vt.edu/pubs/waterquality/426-043/426-043.html
Bay Directory of Native Plant Nurseries http://www.montgomerycountymd.gov/Content/DEP/Rainscapes/nurseries.htm
Delaware Green Technology Standards and Specifications http://www.dnrec.state.de.us/DNREC2000/Divisions/Soil/Stormwater/New/GT_Stds%20&%20Specs_06-05.pdf

The choice of which planting template to use depends on the scale of bioretention, the context of the site in the urban environment, the filter depth, the desired landscape amenities, and the future owner's capability to maintain the landscape. In general, the vegetative goal is to cover up the filter surface with vegetation in a short amount of time. This means that the herbaceous layer is equally or more important than widely-spaced trees and shrubs. In the past, many bioretention areas in Virginia did not include enough herbaceous plants.

The following additional guidance is provided regarding developing an effective bioretention landscaping plan:

- Plants should be selected based on a specified zone of hydric tolerance and must be capable of surviving both wet and dry conditions.

- "Wet footed" species should be planted near the center, whereas upland species do better planted near the edge.

- Woody vegetation should not be located at points of inflow; trees should not be planted directly above underdrains, but should be located closer to the perimeter.

- If trees are part of the planting plan, a tree density of approximately one tree per 250 square feet (i.e., 15 feet on-center) is recommended.

- Shrubs and herbaceous vegetation should generally be planted in clusters and at higher densities (10 feet on-center and 1 to 1.5 feet on-center, respectively).

- Temporary or supplemental irrigation may be needed for the bioretention plantings in order for plant installers to provide a warranty regarding plant material survival.

- Supplemental irrigation by a rain tank system is also recommended (See Stormwater Design Specification No. 6: Rainwater Harvesting).

- Designers should also remember that planting holes for trees need must be at least 4 feet deep to provide enough soil volume for the root structure of mature trees. This applies even if the remaining soil media layer is shallower than 4 feet.

- If trees are used, plant shade-tolerant ground covers within the drip line.

- Maintenance is an important consideration in selecting plant species. Plant selection differs if the area will be frequently mowed, pruned, and weeded, in contrast to a site which will receive minimum annual maintenance.

- If the bioretention area is to be used for snow storage or is to accept snowmelt runoff, it should be planted with salt-tolerant, herbaceous perennials.

6.9. Bioretention Material Specifications

Table 9.6 outlines the standard material specifications used to construct bioretention areas.

Table 9.6. Bioretention Material Specifications

Material	Specification	Notes
Filter Media Composition	Filter Media to contain: • 85%-88% sand • 8%-12% soil fines • 3%-5% organic matter in the form of leaf compost	The volume of filter media based on 110% of the plan volume, to account for settling or compaction.
Filter Media Testing	P-Index range = 10-30, ***OR*** Between 7 and 21 mg/kg of P in the soil media. CECs greater than 10	The media must be procured from approved filter media vendors.
Mulch Layer	Use aged, shredded hardwood bark mulch	Lay a 2 to 3 inch layer on the surface of the filter bed.
Alternative Surface Cover	Use river stone or pea gravel, coir and jute matting, or turf cover.	Lay a 2 to 3 inch layer of to suppress weed growth.
Top Soil For Turf Cover	Loamy sand or sandy loam texture, with less than 5% clay content, pH corrected to between 6 and 7, and an organic matter content of at least 2%.	3 inch surface depth.
Geotextile/Liner	Use a non-woven geotextile fabric with a flow rate of > 110 gal./min./sq. ft. (e.g., Geotex 351 or equivalent)	Apply only to the sides and above the underdrain. For hotspots and certain karst sites only, use an appropriate liner on bottom.
Choking Layer	Lay a 2 to 4 inch layer of sand over a 2 inch layer of choker stone (typically #8 or #89 washed gravel), which is laid over the underdrain stone.	
Stone Jacket for Underdrain and/or Storage Layer	1 inch stone should be double-washed and clean and free of all fines (e.g., VDOT #57 stone).	12 inches for the underdrain; 12 to 18 inches for the stone storage layer, if needed
Underdrains, Cleanouts, and Observation Wells	Use 6 inch rigid schedule 40 PVC pipe (or equivalent corrugated HDPE for micro-bioretention), with 3/8-inch perforations at 6 inches on center; position each underdrain on a 1% or 2% slope located nor more than 20 feet from the next pipe.	Lay the perforated pipe under the length of the bioretention cell, and install non-perforated pipe as needed to connect with the storm drain system. Install T's and Y's as needed, depending on the underdrain configuration. Extend cleanout pipes to the surface with vented caps at the Ts and Ys.
Plant Materials	Plant one tree per 250 square feet (15 feet on-center, minimum 1 inch caliper). Shrubs a minimum of 30 inches high planted a minimum of 10 feet on-center. Plant ground cover plugs at 12 to 18 inches on-center; Plant container-grown plants at 18 to 24 inches on-center, depending on the initial plant size and how large it will grow.	Establish plant materials as specified in the landscaping plan and the recommended plant list. In general, plant spacing must be sufficient to ensure the plant material achieves 80% cover in the proposed planting areas within a 3-year period. If seed mixes are used, they should be from a qualified supplier, should be appropriate for stormwater basin applications, and should consist of native species (unless the seeding is to establish maintained turf).

SECTION 7: REGIONAL & SPECIAL CASE DESIGN ADAPTATIONS

7.1 Karst Terrain

Karst regions are found in much of the Ridge and Valley province of Virginia, which complicates both land development and stormwater design. While bioretention areas produce less deep ponding than conventional stormwater practices (e.g., ponds and wetlands), Level 2 bioretention designs (i.e., infiltration) are not recommended in any area with a moderate or high risk of sinkhole formation (Hyland, 2005). On the other hand, Level 1 designs that meet separation distance requirements (3 feet) and possess an impermeable bottom liner and an underdrain should work well. In general, micro-bioretention and bioretention basins with contributing drainage areas not exceeding 20,000 square feet are preferred (compared to bioretention with larger drainage areas), in order to prevent possible sinkhole formation. However, it may be advisable to increase standard setbacks to buildings.

7.2 Coastal Plain

The flat terrain, low hydraulic head, and high water table of many coastal plain sites can constrain the application of deeper bioretention areas (particularly Level 2 designs). In such settings, the following design adaptations may be helpful:

- A linear approach to bioretention, using multiple cells leading to the ditch system, helps conserve hydraulic head.
- The minimum depth of the filter bed may be 18 to 24 inches. It is useful to limit surface ponding to 6 to 9 inches and avoid the need for additional depth by establishing a turf cover rather than using mulch. The shallower media depth and the turf cover generally comply with the Dry Swale specification, and therefore will be credited with a slightly lower pollutant removal (See Stormwater Design Specification No. 10: Dry Swales).
- The minimum depth to the seasonally high water table from the invert of the system can be 1 foot, as long as the bioretention area is equipped with a large-diameter underdrain (e.g., 6 inches) that is only partially efficient at dewatering the bed.
- It is important to maintain at least a 0.5% slope in the underdrain to ensure positive drainage.
- The underdrain should be tied into the ditch or conveyance system.
- The mix of plant species selected should reflect coastal plain plant communities and should be more wet-footed and salt-tolerant than those used in typical Piedmont applications.

While these design criteria permit bioretention to be used on a wider range of coastal plain sites, it is important not to avoid using bioretention on marginal sites. Other stormwater practices, such as wet swales, ditch wetland restoration, and smaller linear wetlands, are often preferred alternatives for coastal plain sites.

7.3 Steep Terrain

In steep terrain, land with a slope of up to 15% may drain to a bioretention area, as long as a two cell design is used to dissipate erosive energy prior to filtering. The first cell, between the slope and the filter media, functions as a forebay to dissipate energy and settle any sediment that migrates down the slope. Designers may also want to terrace a series of bioretention cells to manage runoff across or down a slope. The drop in slope between cells should be limited to 1 foot and should be armored with river stone or a suitable equivalent.

7.4 Cold Climate and Winter Performance

Bioretention areas can be used for snow storage as long as an overflow is provided and they are planted with salt-tolerant, non-woody plant species. (NOTE: Designers may want to evaluate Chesapeake Bay wetland plant species that tolerate slightly brackish water.) Tree and shrub locations should not conflict with plowing and piling of snow into storage areas.

While several studies have shown that bioretention facilities operate effectively in Pennsylvania and West Virginia winters, it is a good idea to extend the filter bed and underdrain pipe below the frost line and/or oversize the underdrain by one pipe size to reduce the freezing potential.

7.5 Linear Highway Sites

Bioretention is a preferred practice for constrained highway right of ways when designed as a series of individual on-line or off-line cells. In these situations, the final design closely resembles that of dry swales. Salt tolerant species should be selected if salt compounds will be used to de-ice the contributing roadway in the winter.

SECTION 8: CONSTRUCTION

8.1. Construction Sequence

Construction Stage E&S Controls. Micro-bioretention and small-scale bioretention areas should be fully protected by silt fence or construction fencing, particularly if they will rely on infiltration (i.e., have no underdrains). Ideally, bioretention should remain outside the limit of disturbance during construction to prevent soil compaction by heavy equipment. Bioretention basin locations may be used as small sediment traps or basins during construction. However, these must be accompanied by notes and graphic details on the E&S plan specifying that (1) the maximum excavation depth at the construction stage must be at least 1 foot above the post-construction installation, and (2) the facility must contain an underdrain. The plan must also show the proper procedures for converting the temporary sediment control practice to a permanent bioretention facility, including dewatering, cleanout and stabilization.

8.2 Bioretention Installation

The following is a typical construction sequence to properly install a bioretention basin (also see **Figure 9.16**). The construction sequence for micro-bioretention is more simplified. These steps may be modified to reflect different bioretention applications or expected site conditions:

Step 1. Construction of the bioretention area may only begin after the entire contributing drainage area has been stabilized with vegetation. It may be necessary to block certain curb or other inlets while the bioretention area is being constructed. The proposed site should be checked for existing utilities prior to any excavation.

Step 2. The designer and the installer should have a preconstruction meeting, checking the boundaries of the contributing drainage area and the actual inlet elevations to ensure they conform to original design. Since other contractors may be responsible for constructing portions of the site, it is quite common to find subtle differences in site grading, drainage and paving elevations that can produce hydraulically important differences for the proposed bioretention area. The designer should clearly communicate, in writing, any project changes determined during the preconstruction meeting to the installer and the plan review/inspection authority.

Step 3. Temporary E&S controls are needed during construction of the bioretention area to divert stormwater away from the bioretention area until it is completed. Special protection measures such as erosion control fabrics may be needed to protect vulnerable side slopes from erosion during the construction process.

Step 4. Any pre-treatment cells should be excavated first and then sealed to trap sediments.

Step 5. Excavators or backhoes should work from the sides to excavate the bioretention area to its appropriate design depth and dimensions. Excavating equipment should have scoops with adequate reach so they do not have to sit inside the footprint of the bioretention area. Contractors should use a cell construction approach in larger bioretention basins, whereby the basin is split into 500 to 1,000 sq. ft. temporary cells with a 10-15 foot earth bridge in between, so that cells can be excavated from the side.

Step 6. It may be necessary to rip the bottom soils to a depth of 6 to 12 inches to promote greater infiltration.

Step 7. Place geotextile fabric on the sides of the bioretention area with a 6-inch overlap on the sides. If a stone storage layer will be used, place the appropriate depth of #57 stone on the bottom, install the perforated underdrain pipe, pack #57 stone to 3 inches above the underdrain pipe, and add approximately 3 inches of choker stone/pea gravel as a filter between the underdrain and the soil media layer. If no stone storage layer is used, start with 6 inches of #57 stone on the bottom, and proceed with the layering as described above.

Step 8. Deliver the soil media from an approved vendor, and store it on an adjacent impervious area or plastic sheeting. Apply the media in 12-inch lifts until the desired top elevation of the bioretention area is achieved. Wait a few days to check for settlement, and add additional media, as needed, to achieve the design elevation.

Step 9. Prepare planting holes for any trees and shrubs, install the vegetation, and water accordingly. Install any temporary irrigation.

Step 10. Place the surface cover in both cells (mulch, river stone or turf), depending on the design. If coir or jute matting will be used in lieu of mulch, the matting will need to be installed prior to planting (**Step 9**), and holes or slits will have to be cut in the matting to install the plants.

Step 11. Install the plant materials as shown in the landscaping plan, and water them during weeks of no rain for the first two months.

Step 12. Conduct the final construction inspection (see **Section 9.2**). Then log the GPS coordinates for each bioretention facility and submit them for entry into the local maintenance tracking database.

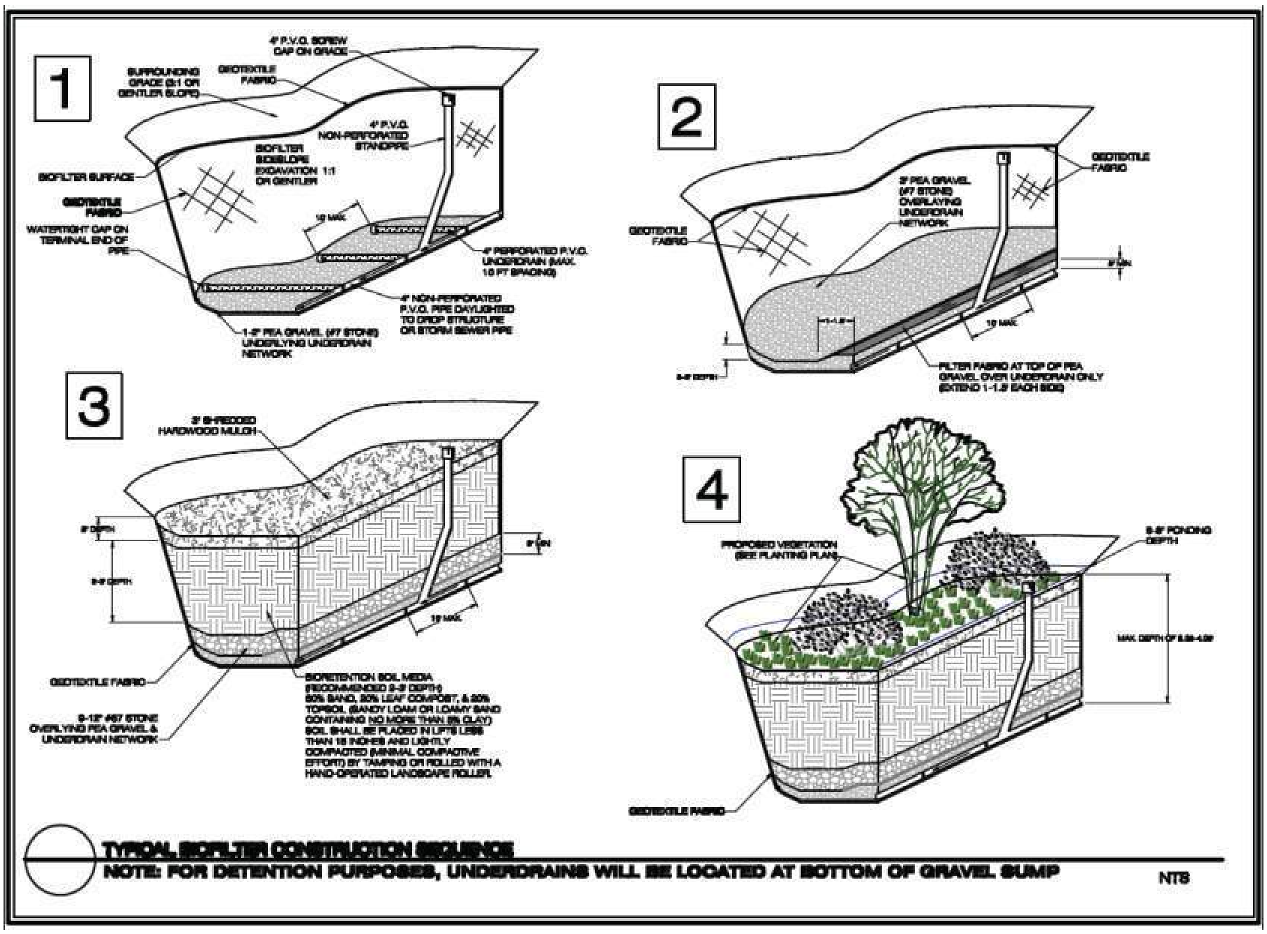


Figure 9.16. Typical Biofilter Construction Sequence

8.3.Construction Inspection

An example construction phase inspection checklist for Bioretention areas can be accessed at the CWP website at:

http://www.cwp.org/Resource_Library/Controlling_Runoff_and_Discharges/sm.htm
(scroll to Tool6: Plan Review, BMP Construction, and Maintenance Checklists)

SECTION 9: MAINTENANCE

9.1. Maintenance Agreements

Section 4 VAC 50-60-124 of the regulations specifies the circumstances under which a maintenance agreement ~~to~~ must be executed between the owner and the local program. This section sets forth inspection requirements, compliance procedures if maintenance is neglected, notification of the local program upon transfer of ownership, and right-of-entry for local program personnel.

For bioretention, maintenance agreements must contain recommended maintenance tasks and a copy of an annual inspection checklist. When micro-scale bioretention practices are applied on private residential lots, homeowners will need to be educated regarding their routine maintenance needs. A deed restriction, drainage easement or other mechanism enforceable by the qualifying local program must be in place to help ensure that rain gardens and bioretention filters are maintained and not converted or disturbed, as well as to pass the knowledge along to any subsequent owners. The mechanism should, if possible, grant authority for local agencies to access the property for inspection or corrective action.

9.2. First Year Maintenance Operations

Successful establishment of bioretention areas requires that the following tasks be undertaken in the first year following installation:

- ***Initial inspections.*** For the first 6 months following construction, the site should be inspected at least twice after storm events that exceed 1/2 inch of rainfall.
- ***Spot Reseeding.*** Inspectors should look for bare or eroding areas in the contributing drainage area or around the bioretention area, and make sure they are immediately stabilized with grass cover.
- ***Fertilization.*** One-time, spot fertilization may be needed for initial plantings.
- ***Watering.*** Watering is needed once a week during the first 2 months, and then as needed during first growing season (April-October), depending on rainfall.
- ***Remove and replace dead plants.*** Since up to 10% of the plant stock may die off in the first year, construction contracts should include a care and replacement warranty to ensure that vegetation is properly established and survives during the first growing season following construction. The typical thresholds below which replacement is required are 85% survival of plant material and 100% survival of trees.

9.3. Maintenance Inspections

It is highly recommended that a spring maintenance inspection and cleanup be conducted at each bioretention area. The following is a list of some of the key maintenance problems to look for:

- Check to see if 75% to 90% cover (mulch plus vegetative cover) has been achieved in the bed, and measure the depth of the remaining mulch.
- Check for sediment buildup at curb cuts, gravel diaphragms or pavement edges that prevents flow from getting into the bed, and check for other signs of bypassing.
- Check for any winter- or salt-killed vegetation, and replace it with hardier species.
- Note presence of accumulated sand, sediment and trash in the pre-treatment cell or filter beds, and remove it.
- Inspect bioretention side slopes and grass filter strips for evidence of any rill or gully erosion, and repair it.
- Check the bioretention bed for evidence of mulch flotation, excessive ponding, dead plants or concentrated flows, and take appropriate remedial action.
- Check inflow points for clogging, and remove any sediment.
- Look for any bare soil or sediment sources in the contributing drainage area, and stabilize them immediately.
- Check for clogged or slow-draining soil media, a crust formed on the top layer, inappropriate soil media, or other causes of insufficient filtering time, and restore proper filtration characteristics.

Example maintenance inspection checklists for Bioretention areas can be accessed in Appendix C of Chapter 9 of the *Virginia Stormwater Management Handbook* (2010) or at the Center for Watershed Protection website at:

http://www.cwp.org/Resource_Library/Controlling_Runoff_and_Discharges/sm.htm
(scroll to Tool6: Plan Review, BMP Construction, and Maintenance Checklists)

9.4. Routine and Non-Routine Maintenance Tasks

Maintenance of bioretention areas should be integrated into routine landscape maintenance tasks. If landscaping contractors will be expected to perform maintenance, their contracts should contain specifics on unique bioretention landscaping needs, such as maintaining elevation differences needed for ponding, proper mulching, sediment and trash removal, and limited use of fertilizers and pesticides. A customized maintenance schedule must be prepared for each bioretention facility, since the maintenance tasks will differ depending on the scale of bioretention, the landscaping template chosen, and the type of surface cover. A generalized summary of common maintenance tasks and their frequency is provided in **Table 9.7**.

The most common non-routine maintenance problem involves standing water. If water remains on the surface for more than 48 hours after a storm, adjustments to the grading may be needed or underdrain repairs may be needed. The surface of the filter bed should also be checked for accumulated sediment or a fine crust that builds up after the first several storm events. There are several methods that can be used to rehabilitate the filter (try the easiest things first, as listed below):

- Open the underdrain observation well or cleanout and pour in water to verify that the underdrains are functioning and not clogged or otherwise in need of repair. The purpose of this check is to see if there is standing water all the way down through the soil. If there is standing water on top, but not in the underdrain, then there is a clogged soil layer. If the underdrain and stand pipe indicates standing water, then the underdrain must be clogged and will need to be snaked.
- Remove accumulated sediment and till 2 to 3 inches of sand into the upper 8 to 12 inches of soil.
- Install sand wicks from 3 inches below the surface to the underdrain layer. This reduces the average concentration of fines in the media bed and promotes quicker drawdown times. Sand wicks can be installed by excavating or augering (using a tree auger or similar tool) down to the gravel storage zone to create vertical columns which are then filled with a clean open-graded coarse sand material (ASTM C-33 concrete sand or similar approved sand mix for bioretention media). A sufficient number of wick drains of sufficient dimension should be installed to meet the design dewatering time for the facility.
- Remove and replace some or all of the soil media.

Table 9.7. Suggested Annual Maintenance Activities for Bioretention

Maintenance Tasks	Frequency
• Mowing of grass filter strips and bioretention turf cover	At least 4 times a year
• Spot weeding, erosion repair, trash removal, and mulch raking	Twice during growing season
• Add reinforcement planting to maintain desired the vegetation density • Remove invasive plants using recommended control methods • Stabilize the contributing drainage area to prevent erosion	As needed
• Spring inspection and cleanup • Supplement mulch to maintain a 3 inch layer • Prune trees and shrubs	Annually
• Remove sediment in pre-treatment cells and inflow points	Once every 2 to 3 years
• Replace the mulch layer	Every 3 years

SECTION 9: REFERENCES

Lake County, OH. *Bioretention Guidance Manual*. Available online at: http://www2.lakecountyohio.org/smd/Forms.htm

CWP. 2007. *National Pollutant Removal Performance Database, Version 3.0*. Center for Watershed Protection, Ellicott City, MD.

Schueler, T. 2008. Technical Support for the Baywide Runoff Reduction Method. Chesapeake Stormwater Network. Baltimore, MD. www.chesapeakestormwater.net

Prince George's Co., MD. *Bioretention Manual*. Available online at: http://www.goprincegeorgescounty.com/Government/AgencyIndex/DER/ESD/Bioretention/bioretention.asp?nivel=foldmenu(7)

Maryland Department of the Environment. 2001. *Maryland Stormwater Design Manual*. http://www.mde.state.md.us/Programs/WaterPrograms/SedimentandStormwater/stormwater_design/index.asp

Wisconsin Department of Natural Resources. *Stormwater Management Technical Standards*. http://www.dnr.state.wi.us/org/water/wm/nps/stormwater/techstds.htm#Post

Hirschman, D., L. Woodworth and S. Drescher. 2009. *Technical Report: Stormwater BMPs in Virginia's James River Basin – An Assessment of Field Conditions and Programs*. Center for Watershed Protection. Ellicott City, MD.

Hunt, W.F. III and W.G. Lord. 2006. "Bioretention Performance, Design, Construction, and Maintenance." *North Carolina Cooperative Extension Service Bulletin.* Urban Waterways Series. AG-588-5. North Carolina State University. Raleigh, NC.

Hyland, S. 2005. "Analysis of sinkhole susceptibility and karst distribution in the Northern Shenandoah Valley (Virginia): impacts for LID site suitability models." M.S. Thesis. Virginia Polytechnic Institute and State University. Blacksburg, VA.

Minnesota Stormwater Steering Committee (MSSC). 2005. *The Minnesota Stormwater Manual*.

Schueler et al. 2007. *Urban Stormwater Retrofit Practices*. Manual 3 in the Urban Subwatershed Restoration Manual Series. Center for Watershed Protection. Ellicott City, MD.

North Shore City. 2007. *Bioretention Design Guidelines*. Sinclair, Knight and Merz. Auckland, New Zealand.

In addition, the following individuals provided review and input for this version of the specification. Rick Scafidi (EQR), Bill Hunt (NCSU), Scott Thomas (JCC), Dave Hirschman (CWP) Don Rissmeyer (VA ASCE), Randy Greer (DENRC), Doug Biesch (WEG), Stuart Stein (GKY), Tim Schueler (MC), Christie Minami (MD SHA). Special thanks to the staff at WEG for providing the design schematics and details.

APPENDIX 9-A

URBAN BIORETENTION

Stormwater Planters
Expanded Tree Pits
Stormwater Curb Extensions

VERSION 1.7
March 8, 2010

SECTION 9-A-1: DESCRIPTION

Urban bioretention practices are similar in function to regular bioretention practices except they are adapted to fit into "containers" within urban landscapes. Typically, urban bioretention is installed within an urban streetscape or city street right-of-way, urban landscaping beds, tree pits and plazas, or other features within an *Urban Development Area*. Urban bioretention is not intended for large commercial areas, nor should it be used to treat small sub-areas of a large drainage area such as a parking lot. Rather, urban bioretention is intended to be incorporated into small fragmented drainage areas such as shopping or pedestrian plazas within a larger urban development.

Urban bioretention features hard edges, often with vertical concrete sides, as contrasted with the more gentle earthen slopes of regular bioretention. These practices may be open-bottomed, to allow some infiltration of runoff into the sub-grade, but they generally are served by an underdrain.

Stormwater planters (also known as vegetative box filters or foundation planters) take advantage of limited space available for stormwater treatment by placing a soil filter in a container located above ground or at grade in landscaping areas between buildings and roadways (**Figure 9-A.1**). The small footprint of foundation planters is typically contained in a precast or cast-in-place concrete vault. Other materials may include molded polypropylene cells and precast modular block systems.

Figure 9-A.1. Stormwater Planters

Extended tree pits are installed in the sidewalk zone near the street where urban street trees are normally installed. The soil volume for the tree pit is increased and used as a stormwater (**Figure 9-A.2**). Treatment is increased by using a series of connected tree planting areas together in a row. The surface of the enlarged planting area may be mulch, grates, permeable pavers, or conventional pavement. The large and shared rooting space and a reliable water supply increase the growth and survival rates in this otherwise harsh planting environment.

Figure 9-A.2. Expanded Tree Pits

Stormwater curb extensions (also known as parallel bioretention) are installed in the road right-of way either in the sidewalk area or in the road itself. In many cases, curb extensions serve as a traffic calming or street parking control device. The basic design adaptation is to move the raised concrete curb closer to the street or in the street, and then create inlets or curb cuts that divert street runoff into depressed vegetated areas within the expanded right of way (**Figure 9-A.3**).

Figure 9-A.3. Stormwater Curb Extensions

Each urban bioretention variant is planted with a mix of trees, shrubs, and grasses as appropriate for its size and landscaping context.

SECTION 9-A-2: PERFORMANCE

The typical stormwater functions of an urban bioretention area are described in **Table 9-A.1**. The three major design variants of urban bioretention are described below:

Table 9-A.1. Summary of Stormwater Functions Provided by Urban Bioretention Areas

Stormwater Function	Level 1 Design	Level 2 Design
Annual Runoff Volume Reduction (RR)	40% (for Water Quality credit in the RRM spreadsheet only) 0% credit for Channel Protection	NA
Total Phosphorus (TP) EMC Reduction[1] by BMP Treatment Process	25%	NA
Total Phosphorus (TP) Mass Load Removal	55%	
Total Nitrogen (TN) EMC Reduction[1] by BMP Treatment Process	40%	NA
	64%	
Channel Protection	None; or if sized according to Bioretention Basin, follow the Level 1 Bioretention basin criteria.	
Flood Mitigation	None	
[1] Change in the event mean concentration (EMC) through the practice. The actual nutrient mass load removed is the product of the removal rate and the runoff reduction rate (see Table 1 in the *Introduction to the New Virginia Stormwater Design Specifications*).		

Sources: CWP and CSN (2008) and CWP (2007)

SECTION 9-A-3: DESIGN TABLE

Table 9-A.2. Urban Bioretention Design Criteria

Level 1 Design Only (RR: 40; TP: 25)
Sizing (Refer to **Section 9-A-6.1**): Surface Area (sq. ft.) = $T_V/2$ = {[(1.0 inch)(R_V)(A)/12)] – the volume reduced by an upstream BMP}/2
Underdrain = Schedule 40 PVC with clean-outs (Refer to the Main Bioretention Design Specification, **Section 9.8**)
Maximum Drainage Area = 2,500 sq. ft.
Maximum Ponding Depth = 6 to 12 inches [1]
Filter media depth minimum = 30 inches; recommended maximum = 48 inches
Media and Surface Cover (Refer to the Main Bioretention Design Specification, **Section 9.8**)
Sub-soil testing (Refer to the Main Bioretention Design Specification, **Section 9.8**)
Inflow = sheetflow, curb cuts, trench drains, roof drains, concentrated flow, or equivalent
Building setbacks (Refer to **Section ~~A-4~~ 9-A-5**)
Deeded maintenance O&M plan (Refer to the Main Bioretention Design Specification, **Section 9.1**)
[1] Ponding depth above 6 inches will require a specific planting plan to ensure appropriate plants (Refer to the Main Bioretention Design Specification, **Section 6.8**).

SECTION 9-A-4: TYPICAL DETAILS

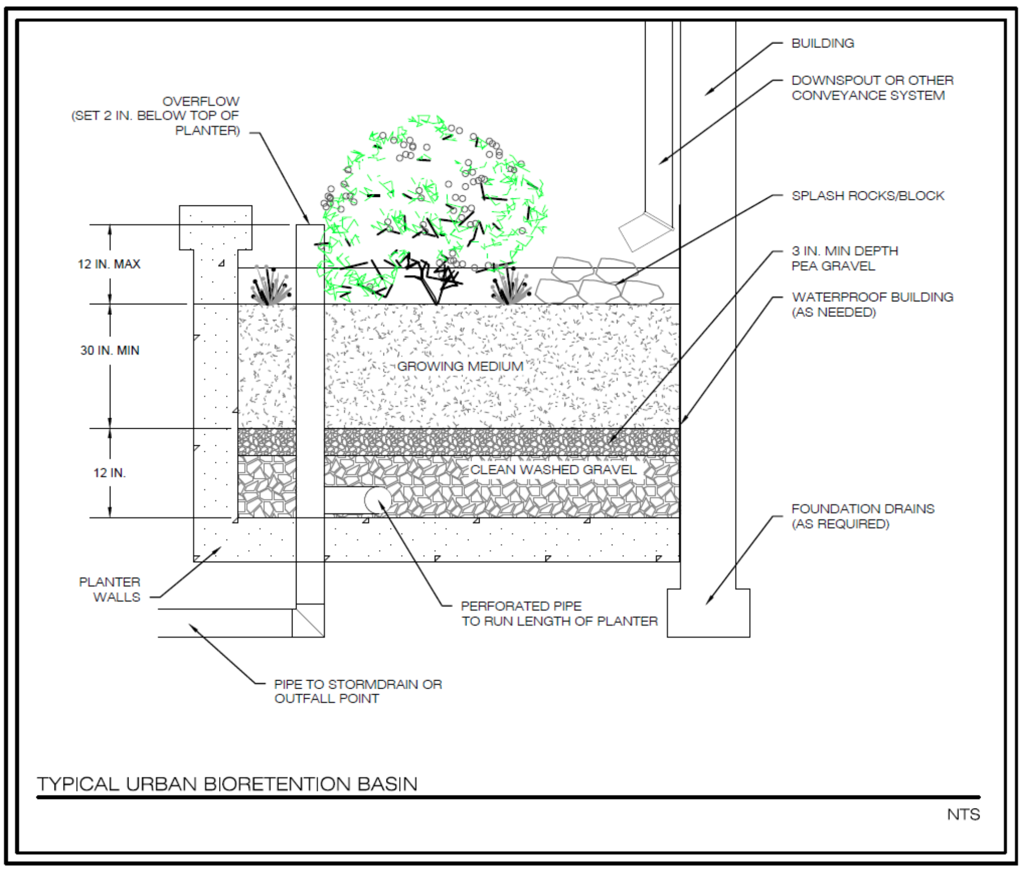


Figure 9-A.4. Stormwater Planter Cross-Section

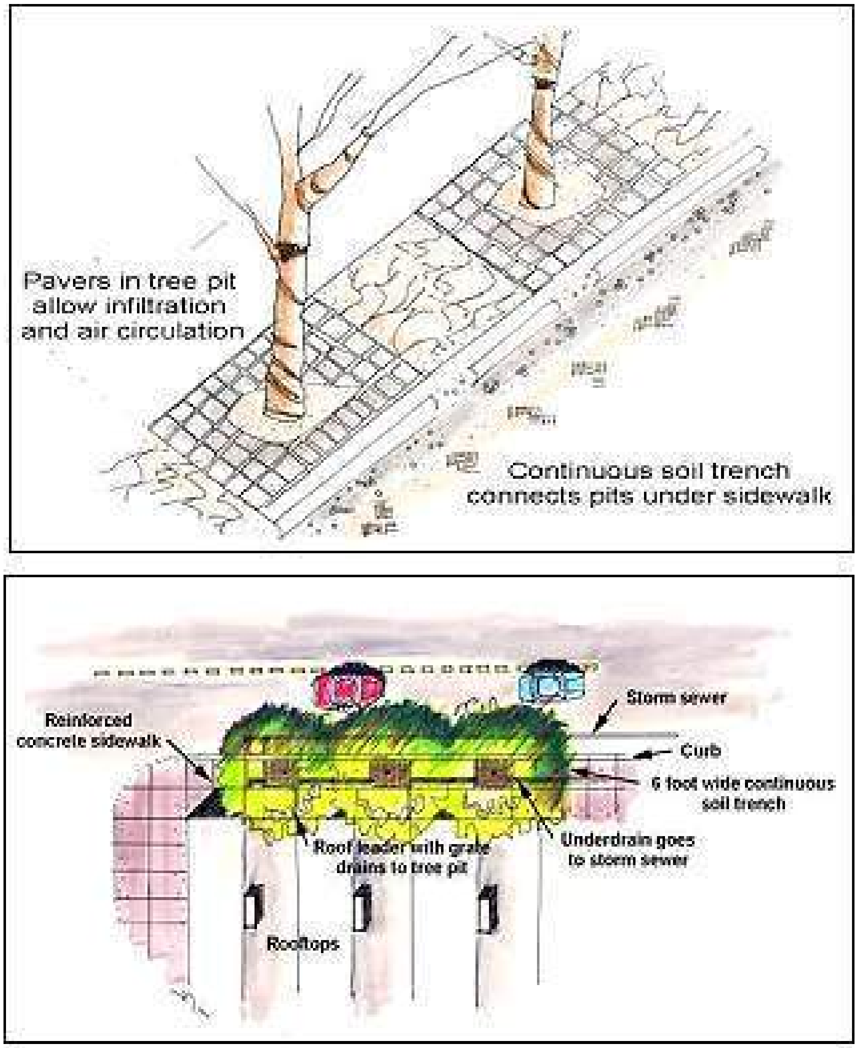


Figure 9-A.5. Expanded Tree Pit Details

Portland, Oregon (Portland BES, 2004) has thorough construction details for stormwater curb extensions, expanded tree pits, and utility house connections, available online at http://www.portlandonline.com/bes/index.cfm?c=44213& .

SECTION 9-A-5: PHYSICAL FEASIBILITY & DESIGN APPLICATIONS

In general, urban bioretention has the same constraints as regular bioretention, along with a few additional constraints as noted below:

Contributing Drainage Area. Urban bioretention is classified as a micro-bioretention practice and is therefore limited to 2,500 sq. ft. of drainage area to each unit. However, this is considered a general rule; larger drainage areas may be allowed with sufficient flow controls and other mechanisms to ensure proper function, safety, and community acceptance. The drainage areas in these urban settings are typically considered to be 100% impervious. While multiple units can be installed to maximize the treatment area in ultra-urban watersheds, urban bioretention is not intended to be used as treatment for large impervious areas (such as parking lots).

Adequate Drainage. Urban bioretention practice elevations must allow the untreated stormwater runoff to be discharged at the surface of the filter bed and ultimately connect to the local storm drain system.

Available Hydraulic Head. In general, 3 to 5 feet of elevation difference is needed between the downstream storm drain invert and the inflow point of the urban bioretention practice. This is generally not a constraint, due to the standard depth of most storm drains systems.

Setbacks from Buildings ~~Roads~~. If an impermeable liner and an underdrain are used, no setback is needed from the building. Otherwise, the standard 10 foot down-gradient setback applies.

Proximity to Underground Utilities. Urban bioretention practices frequently compete for space with a variety of utilities. Since they are often located parallel to the road right-of-way, care should be taken to provide utility-specific horizontal and vertical setbacks. However, conflicts with water and sewer laterals (e.g., house connections) may be unavoidable, and the construction sequence must be altered, as necessary, to avoid impacts to existing service.

Overhead Wires. Designers should also check whether future tree canopy heights achieved in conjunction with urban bioretention practices will interfere with existing overhead telephone, cable communications and power lines.

Minimizing External Impacts. Because urban bioretention practices are installed in ~~a~~ highly urban settings, individual units may be subject to higher public visibility, greater trash loads, pedestrian ~~use~~ traffic, vandalism, and even vehicular loads. Designers should design these practices in ways that prevent, or at least minimize, such impacts. In addition, designers should clearly recognize the need to perform frequent landscaping maintenance to remove trash, check for clogging, and maintain vigorous vegetation. The urban landscape context may feature naturalized landscaping or a more formal deign. When urban bioretention is used in sidewalk areas of high foot traffic, designers should not impede pedestrian movement or create a safety hazard. Designers may also install low fences, grates or other measures to prevent damage from pedestrian short-cutting across the practices.

SECTION 9-A-6: DESIGN CRITERIA

Urban bioretention practices are similar in function to regular bioretention practices except they are adapted to fit into “containers” within urban landscapes. Therefore, special sizing accommodations are made to allow these practices to fit in very constrained areas where other surface practices may not be feasible.

6.1. Sizing of Urban Bioretention

The required surface area of the urban bioretention filter is one-half of the Treatment Volume (**Equation 9-A.1** below). This criterion represents a balance between the need to size these structures so as to provide a reasonable alternative in ultra urban settings and the relationship between the surface area size, media permeability, and drawdown requirements. Ideally, urban bioretention facilities are in close proximity to the public or users of the adjacent buildings and/or commercial areas, and thus subjected to increased scrutiny. This provides a theoretical basis for adjusting the clogging factor for the media permeability coefficient (k, ft/day), or an increase in the allowable maximum drawdown time, resulting in the smaller sizing. However, as a result, Level 1 urban bioretention will only count towards water quality credit through the 40% volume reduction and/or the 25% TP pollutant removal. There is no credit given to channel protection due to the reduced surface area and storage volume.

Equation 9-A.1. Urban Bioretention Sizing

$$SA \text{ (sq. ft.)} = T_v \text{ (cu. ft.)} / 2.0 \text{ ft.}$$

Where:

SA = the surface area of the urban bioretention facility (in square feet)

T_v = the required Treatment Volume (in cubic feet)

6.2 General Design Criteria for Urban Bioretention

Design of urban bioretention should follow the general guidance presented in the main part of this Bioretention design specification. The actual geometric design of urban bioretention is usually dictated by other landscape elements such as buildings, sidewalk widths, utility corridors, retaining walls, etc. Designers can divert fractions of the runoff volume from small impervious surfaces into micro-bioretention units that are integrated with the overall landscape design. Inlets and outlets should be located as far apart as possible. The following is additional design guidance that applies to all variations of urban bioretention:

- The ground surface of the micro-bioretention cell should slope 1% towards the outlet, unless a stormwater planter is used.
- The soil media depth should be a minimum of 30 inches.
- If large trees and shrubs are to be installed, soil media depths should be a minimum of 4 feet.
- Each individual urban bioretention unit should be stenciled or otherwise permanently marked to designate it as a stormwater management facility. The stencil or plaque should indicate (1) its water quality purpose, (2) that it may pond briefly after a storm, and (3) that it is not to be disturbed except for required maintenance.
- All urban bioretention practices should be designed to fully drain within 24 hours.
- Any grates used above urban bioretention areas must be removable to allow maintenance access.
- The inlet(s) to urban bioretention should be stabilized using VDOT #3 stone, splash block, river stone or other acceptable energy dissipation measures. The following forms of inlet stabilization are recommended:

  - Downspouts to stone energy dissipators.
  - Sheet flow over a depressed curb with a 3-inch drop.
  - Curb cuts allowing runoff into the bioretention area.
  - Covered drains that convey flows across sidewalks from the curb or downspouts.
  - Grates or trench drains that capture runoff from the sidewalk or plaza area.
- Pre-treatment options overlap with those of regular bioretention practices. However, the materials used may be chosen based on their aesthetic qualities in addition to their functional properties. For example, river rock may be used in lieu of rip rap. Other pretreatment options may include one of the following:
  - A trash rack between the pre-treatment cell and the main filter bed. This will allow trash to be collected from one location.
  - A trash rack across curb cuts. While this trash rack may clog occasionally, it keeps trash in the gutter, where it can be picked up by street sweeping equipment.
  - A pre-treatment area above ground or a manhole or grate directly over the pre-treatment area.
- Overflows can either be diverted from entering the bioretention cell or dealt with via an overflow inlet. Optional methods include the following:
  - Size curb openings to capture only the Treatment Volume and bypass higher flows through the existing gutter.
  - Use landscaping type inlets or standpipes with trash guards as overflow devices.
  - Use a pre-treatment chamber with a weir design that limits flow to the filter bed area.

6.3 Specific Design Issues for Stormwater Planters

Since stormwater planters are often located near building foundations, waterproofing by using a watertight concrete shell or an impermeable liner is required to prevent seepage.

6.4 Specific Design Issues for Expanded Tree Pits

- The bottom of the soil layer must be a minimum of 4 inches below the root ball of plants to be installed.
- Extended tree pits designs sometimes cover portions of the filter media with pervious pavers or cantilevered sidewalks. In these situations, it is important that the filter media is connected beneath the surface so that stormwater and tree roots can share this space.
- Installing a tree pit grate over filter bed media is one possible solution to prevent pedestrian traffic and trash accumulation.
- Low, wrought iron fences can help restrict pedestrian traffic across the tree pit bed and serve as a protective barrier if there is a dropoff from the pavement to the micro-bioretention cell.
- A removable grate capable of supporting typical H-20 axel loads may be used to allow the tree to grow through it.
- Each tree needs a minimum of 400 cubic feet of shared root space.

6.5 Specific Design Issues for Stormwater Curb Extensions

Roadway stability can be a design issue where stormwater curb extensions are installed. Consult design standards pertaining to roadway drainage. It may be necessary to provide a barrier to keep water from saturating the road's sub-base and demonstrate it is capable of supporting H-20 axel loads.

6.6 Planting and Landscaping Considerations

The degree of landscape maintenance that can be provided will determine some of the planting choices for urban bioretention areas. The planting cells can be formal gardens or naturalized landscapes.

In areas where less maintenance will be provided and where trash accumulation in shrubbery or herbaceous plants is a concern, consider a "turf and trees" landscaping model. Spaces for herbaceous flowering plants can be included. This may be attractive at a community entrance location.

Native trees or shrubs are preferred for urban bioretention areas, although some ornamental species may be used. As with regular bioretention, the selected perennials, shrubs, and trees must be tolerant of salt, drought, and inundation. Additionally, tree species should be those that are known to survive well in the compacted soils and polluted air and water of an urban landscape.

SECTION 9-A-7: URBAN BIORETENTION MATERIAL SPECIFICATIONS

Please consult the **main part of this design specification** (**Table 9.6**) for the typical materials needed for filter media, stone, mulch and other bioretention features. The unique components for urban bioretention may include the inlet control device, a concrete box or other containing shell, protective grates, and an underdrain that daylights to another stormwater practice or connects to the storm drain system. The underdrain should:

- Consist of slotted pipe greater than or equal to 4 inches in diameter, placed in a layer of washed (less than 1% passing a #200 sieve) VDOT #57 stone.
- Have a minimum of 2 inches of gravel laid above and below the pipe.
- Be laid at a minimum slope of 0.5 %.
- Extend the length of the box filter from one wall to within 6 inches of the opposite wall, and may be either centered in the box or offset to one side.
- Be separated from the soil media by non-woven, geotextile fabric or a 2 to 3 inch layer of either washed VDOT #8 stone or 1/8 to 3/8 inch pea gravel.

SECTION 9-A.8: CONSTRUCTION

The construction sequence and inspection requirements for urban bioretention are generally the same as micro-bioretention practices. Consult the construction sequence and inspection guidance provided in **the main part of this design specification**. In cases where urban bioretention is constructed in the road or right-of-way, the construction sequence may need to be adjusted to account for traffic control, pedestrian access and utility notification.

Urban bioretention areas should only be constructed after the drainage area to the facility is completely stabilized. The specified growth media should be placed and spread by hand with minimal compaction, in order to avoid compaction and maintain the porosity of the media. The media should be placed in 8 to 12 inch lifts with no machinery allowed directly on the media during or after construction. The media should be overfilled above the proposed surface elevation, as needed, to allow for natural settling. Lifts may be lightly watered to encourage settling. After the final lift is placed, the media should be raked (to level it), saturated, and allowed to settle for at least one week prior to installation of plant materials.

SECTION 9-A-9: MAINTENANCE

Routine operation and maintenance are essential to gain public acceptance of highly visible urban bioretention areas. Weeding, pruning, and trash removal should be done as needed to maintain the aesthetics necessary for community acceptance. During drought conditions, it may be necessary to water the plants, as would be necessary for any landscaped area.

To ensure proper performance, inspectors should check that stormwater infiltrates properly into the soil within 24 hours after a storm. If excessive surface ponding is observed, corrective measures include inspection for soil compaction and underdrain clogging. Consult the maintenance guidance outlined in **the main part of this design specification**.

SECTION 9-A-10: DESIGN REFERENCES

Center for Watershed Protection. 2006. *Urban Watershed Forestry Manual. Part 2: Conserving and Planting Trees at Development Sites.* Ellicott City, MD. Available online at: http://www.cwp.org/forestry/index.htm

City of Portland. Bureau of Environmental Services. (Portland BES). 2004. *Portland Stormwater Management Manual*. Portland, OR. http://www.portlandonline.com/bes/index.cfm?c=dfbcc

Credit Valley Conservation. 2008. *Credit River Stormwater Management Manual*. Mississauga, Ontario.

Northern Virginia Regional Commission. 2007. *Low Impact Development Supplement to the Northern Virginia BMP Handbook.* Fairfax, Virginia

Saxton, K.E., W.J. Rawls, J.S. Romberger, and R.I. Papendick. 1986. "Estimating generalized soil-water characteristics from texture." *Soil Sci. Soc. Am. J.* 50(4):1031-1036.

Schueler, T., D. Hirschman, M. Novotney and J. Zielinski. 2007. *Urban stormwater retrofit practices.* Manual 3 in the Urban Subwatershed Restoration Manual Series. Center for Watershed Protection, Ellicott City, MD.

APPENDIX 9-B

ADDITIONAL DETAILS AND SCHEMATICS FOR REGULAR BIORETENTION PRACTICES

VERSION 1.6
September 31, 2009

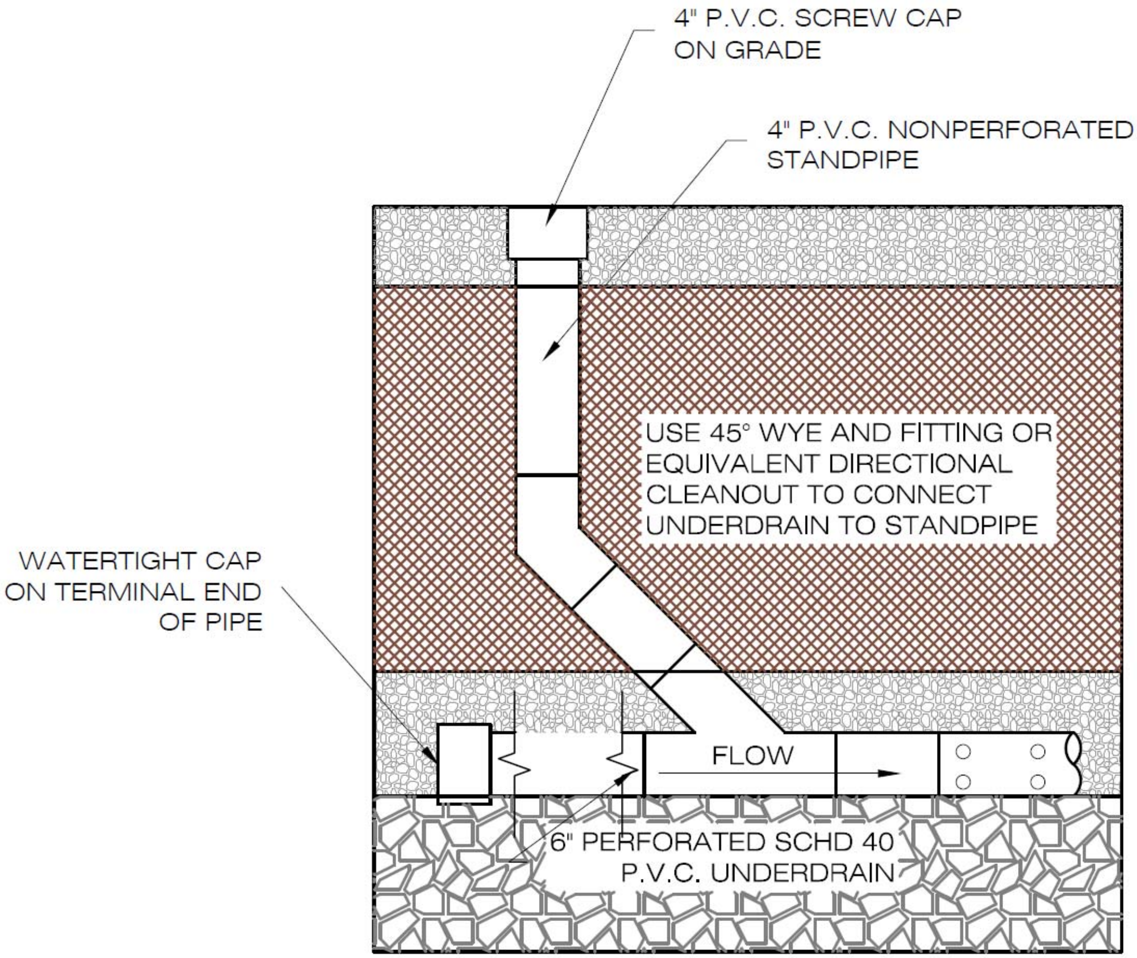


Figure 9-B.1. 4" P.V.C. Cleanout Detail

BIOFILTER PLANTING SPECIFICATIONS:

FROM VIRGINIA STORMWATER MANAGEMENT HANDBOOK

1. ROOT STOCK OF THE PLANT MATERIAL SHALL BE KEPT MOIST DURING TRANSPORT FROM THE SOURCE TO THE JOB SITE AND UNTIL PLANTED.

2. WALLS OF PLANTING PIT SHALL BE DUG SO THAT THEY ARE VERTICAL.

3. THE DIAMETER OF THE PLANTING PIT MUST BE A MINIMUM OF SIX INCHES (6") LARGER THAN THE DIAMETER OF THE BALL OF THE TREE.

4. THE PLANTING PIT SHALL BE DEEP ENOUGH TO ALLOW 1/8 OF THE OVERALL DIMENSION OF THE ROOT BALL TO BE ABOVE GRADE. LOOSE SOIL AT THE BOTTOM OF THE PIT SHALL BE TAMPED BY HAND.

5. THE APPROPRIATE AMOUNT OF FERTILIZER IS TO BE PLACED AT THE BOTTOM OF THE PIT (SEE BELOW FOR FERTILIZATION RATES).

6. THE PLANT SHALL BE REMOVED FROM THE CONTAINER AND PLACED IN THE PLANTING PIT BY LIFTING AND CARRYING THE PLANT BY ITS' BALL (NEVER LIFT BY BRANCHES OR TRUNK).

7. SET THE PLANT STRAIGHT AND IN THE CENTER OF THE PIT SO THAT APPROXIMATELY 1/8 OF THE DIAMETER OF THE ROOT BALL IS ABOVE THE FINAL GRADE.

8. BACKFILL PLANTING PIT WITH EXISTING SOIL.

9. MAKE SURE PLANT REMAINS STRAIGHT DURING BACKFILLING PROCEDURE.

10. NEVER COVER THE TOP OF THE BALL WITH SOIL. MOUND SOIL AROUND THE EXPOSED BALL.

11. TREES SHALL BE BRACED BY USING 2" BY 2" WHITE OAK STAKES. STAKES SHALL BE PLACED PARALLEL TO WALKWAYS AND BUILDINGS. STAKES ARE TO BE EQUALLY SPACED ON THE OUTSIDE OF THE TREE BALL. UTILIZING HOSE AND WIRE THE TREE IS BRACED TO THE STAKES.

12. BECAUSE OF THE HIGH LEVELS OF NUTRIENTS IN STORMWATER RUNOFF TO BE TREATED, BIORETENTION BASIN PLANTS SHOULD NOT REQUIRE CHEMICAL FERTILIZATION.

ADDITIONAL PLANTING NOTES

SEE PLANT SCHEDULE FOR SPECIFIC PLANT SPECIES.

1. THE CONTRACTOR SHALL BE RESPONSIBLE FOR LAYOUT OF ALL WORK COVERED UNDER THESE PLANS.

2. LANDSCAPE CONTRACTOR SHALL REFER TO THE STANDARDIZED LANDSCAPE SPECIFICATIONS FOR THE STATE OF VIRGINIA FOR ADDITIONAL INFORMATION. THE CONTRACTOR SHALL ABIDE BY ITS CONTENTS; HOWEVER ANY NOTES OR SPECIFICATIONS ON PLANS SHALL SUPERSEDE THOSE OUTLINED IN THE SPECIFICATIONS MANUAL. (COPIES ARE AVAILABLE FOR A FEE FROM THE VIRGINIA CHAPTER OF THE AMERICAN SOCIETY OF LANDSCAPE ARCHITECTS, VIRGINIA NURSERYMEN'S ASSOCIATION, INC. AND THE VIRGINIA SOCIETY OF LANDSCAPE DESIGNERS.)

3. ALL PLANT MATERIAL SHALL MEET THE MINIMUM SPECIFICATIONS AND STANDARDS DESCRIBED IN THE CURRENT ISSUE OF "THE AMERICAN STANDARD FOR NURSERY STOCK", PUBLISHED BY THE AMERICAN ASSOCIATION OF NURSERYMEN, 1250 I STREET, N.W., SUITE 500, WASHINGTON, D.C. 20005.

4. THE CONTRACTOR SHALL VERIFY ALL DIMENSIONS IN THE FIELD AND NOTIFY THE DESIGNER OF ANY VARIANCE FROM THE PLAN.

5. THE LANDSCAPE CONTRACTOR IS RESPONSIBLE FOR VERIFYING THE LOCATION OF ANY ONSITE UTILITIES (CALL MISS UTILITY 1-800-552-7001 BEFORE ANY EXCAVATION.)

6. REFER TO FINAL SITE PLANS (UNDER SEPARATE COVER) FOR ANY DETAILED SITE INFORMATION.

7. ALL WORK SHALL BE COORDINATED WITH OTHER TRADES.

8. PLANTS WILL BE PREPARED FOR SHIPMENT IN A MANNER THAT WILL NOT CAUSE DAMAGE TO THE BARK, BUDS, BRANCHES, STEMS, OR OVERALL SHAPE OF THE STOCK. CONTAINER GROWN PLANTS WILL BE TRANSPORTED IN THE CONTAINERS IN WHICH THEY HAVE BEEN GROWN.

9. ALL PLANT MATERIAL, UNLESS OTHERWISE SPECIFIED, SHALL BE UNIFORMLY BRANCHED AND HAVE A VIGOROUS ROOT SYSTEM. PLANT MATERIAL SHALL BE HEALTHY, VIGOROUS, AND FREE FROM DEFECTS, DECAY, DISEASES, INSECT PEST EGGS, AND ALL FORMS OF INFESTATION. ALL PLANT MATERIAL SHALL BE FRESH, FREE FROM TRANSPLANT SHOCK OR VISIBLE WILT. PLANTS DEEMED UNHEALTHY WILL BE REJECTED.

10. ALL CONTAINER STOCK SHALL HAVE BEEN PROPAGATED IN A CONTAINER LONG ENOUGH FOR THE ROOT SYSTEM TO HAVE DEVELOPED SUFFICIENTLY TO HOLD ITS SOIL. CONTAINER STOCK WITH POORLY DEVELOPED ROOT SYSTEMS WILL NOT BE ACCEPTED.

11. PLANTS NOT INSTALLED ON THE DAY OF ARRIVAL ON SITE SHALL BE STORED AND PROTECTED BY THE CONTRACTOR. OUTSIDE STORAGE AREAS WILL BE SHADED AND PROTECTED FROM THE WIND AND SUN. PLANTS STORED ON SITE SHALL BE PROTECTED FROM ANY DRYING AT ALL TIMES BY COVERING THE BALLS OR ROOTS WITH MOIST SAWDUST, WET BURLAP, WOOD CHIPS, SHREDDED BARK, PEAT MOSS, OR OTHER SIMILAR MULCHING MATERIAL.

12. THE OWNER RESERVES THE RIGHT TO SUBSTITUTE PLANT MATERIAL TYPE, SIZE AND/OR QUANTITY. ANY SUBSTITUTIONS MUST BE APPROVED BY THE DESIGNER (WEG).

13. MINOR FIELD ADJUSTMENTS MAY BE NECESSARY DUE TO SITE CONDITIONS (EX: ROOTBALL AND UTILITY CONFLICT) MAJOR ADJUSTMENTS MUST BE APPROVED BY DESIGNER.

14. NO PLANTING SHALL OCCUR WHEN THE SOIL IS FROZEN.

15. PLANT MATERIAL SHALL BE PLACED IN EXISTING SOIL WITH EACH PLANTING PIT EXCAVATED TO A SIZE SUFFICIENT TO CONTAIN THE ENTIRE ROOT BALL OR ROOT MASS, WITHOUT CRAMPING ROOT STOCK.

16. THE CONTRACTOR SHALL MAINTAIN A ONE (1) CALENDAR YEAR 80% CARE AND REPLACEMENT WARRANTY FOR ALL PLANTINGS. THE PERIOD OF CARE AND REPLACEMENT SHALL BEGIN AFTER INSPECTION AND APPROVAL OF THE COMPLETE INSTALLATION OF ALL PLANTS AND CONTINUE FOR ONE CALENDAR YEAR.

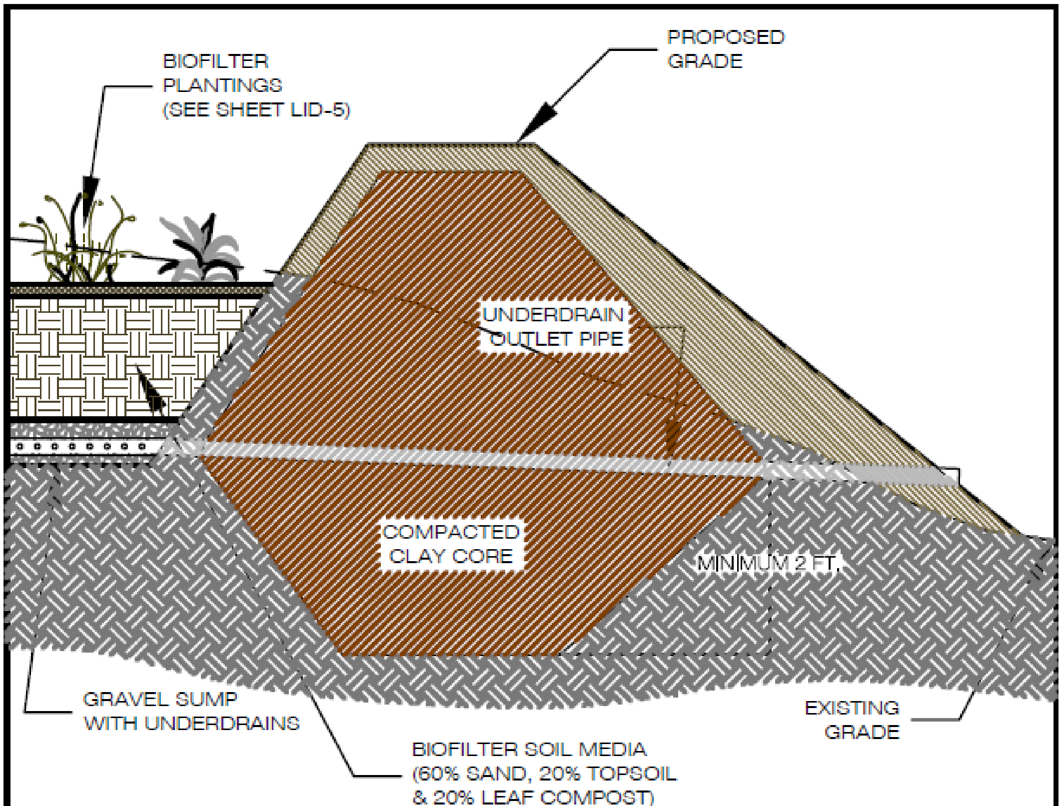
17. THE CONTRACTOR IS RESPONSIBLE FOR REMOVAL AND DISPOSAL OF TRASH AND DEBRIS WITHIN THE LIMITS OF THE PLANTING ON A DAILY BASIS.

18. THE CONTRACTOR WILL NOT BE RESPONSIBLE FOR PLANT MATERIAL THAT HAS BEEN DAMAGED BY VANDALISM, FIRE, OR OTHER ACTIVITIES BEYOND THE CONTRACTOR'S CONTROL.

19. THE CONTRACTOR SHALL CONTACT THE WATER RESOURCES INSPECTOR 24 HOURS PRIOR TO BACKFILLING THE BIOFILTERS AND REQUEST AN INSPECTION AND APPROVAL OF THE UNDERDRAIN INSTALLATION AND THE SOIL MIX.

20. THE BIOFILTER PLANTING AREAS SHALL BE COVERED WITH HEAVY STRAW MULCH TO A DEPTH OF 4" IMMEDIATELY AFTER PLANTING.

Figure 9-B.2. Typical Biofilter Planting Specifications



NOTES:

1) STABILIZE BERM AND SPILLWAYS WITH EC-3 MATTING.

2) REMAINING DISTURBED SLOPES SHALL BE STABILIZED WITH EC-2 MATTING.

3) ALL BERM FILL MATERIAL SHALL CONSIST OF ML, CL, SC, OR GC SOILS AND FREE OF WOOD, ROOTS, ROCKS, OR ANY OTHER NONCOMPACTIBLE SOIL. COMPACTED FILL SHALL BE INSTALLED IN MAXIMUM 6 INCH LIFTS TO A DRY DENSITY OF 95% OF THE STANDARD PROCTOR MAXIMUM DRY DENSITY ASTM D698.

DETAIL: TYPICAL BIOFILTER BERM

NTS

Figure 9-B.3. Typical Bioretention Basin Berm

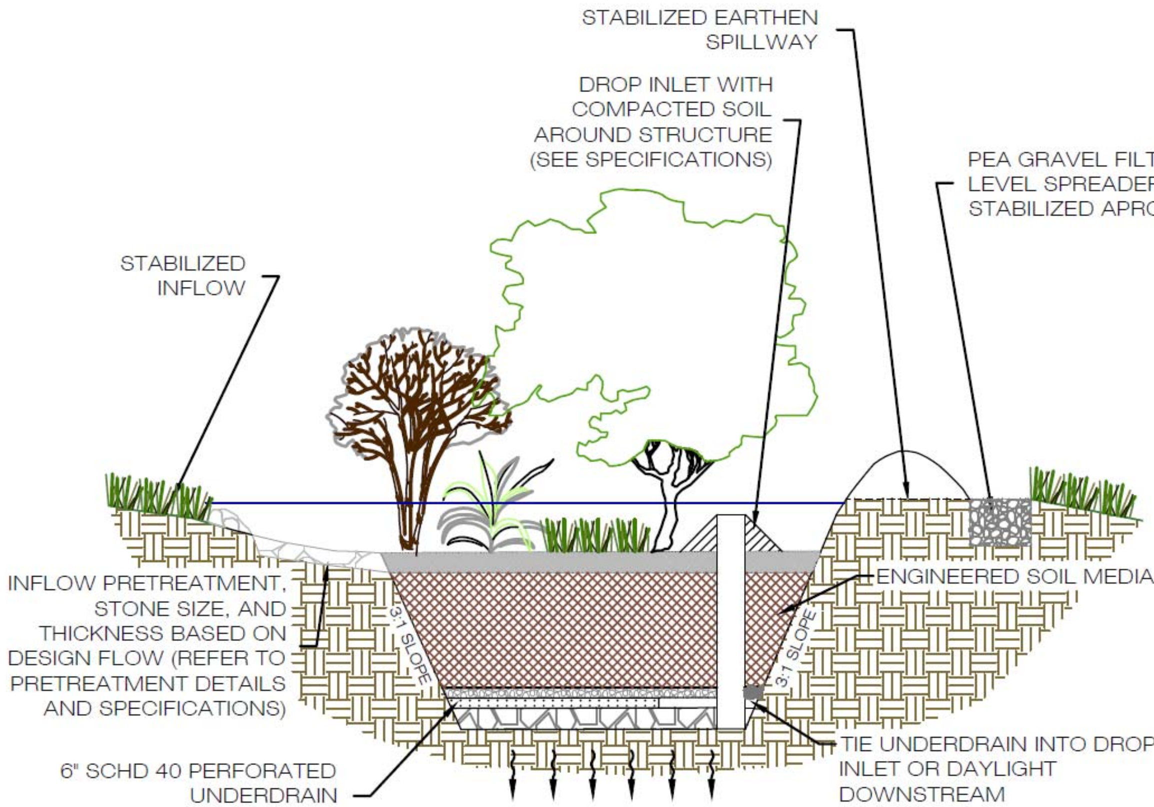


Figure 9-B.4. Typical Bioretention Basin – Inflow & Outflow - Section

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 10

DRY SWALES

VERSION 1.9
March 1, 2011

SECTION 1: DESCRIPTION

Dry swales are essentially bioretention cells that are shallower, configured as linear channels, and covered with turf or other surface material (other than mulch and ornamental plants).

The dry swale is a soil filter system that temporarily stores and then filters the desired Treatment Volume (T_v). Dry swales rely on a pre-mixed soil media filter below the channel that is similar to that used for bioretention. If soils are extremely permeable, runoff infiltrates into underlying soils. In most cases, however, the runoff treated by the soil media flows into an underdrain, which conveys treated runoff back to the conveyance system further downstream. The underdrain system consists of a perforated pipe within a gravel layer on the bottom of the swale, beneath the filter media. Dry swales may appear as simple grass channels with the same shape and turf cover, while others may have more elaborate landscaping. Swales can be planted with turf grass, tall meadow grasses, decorative herbaceous cover, or trees.

SECTION 2: PERFORMANCE

The primary pollutant removal mechanisms operating in swales are settling, filtering infiltration and plant uptake. The overall stormwater functions of the dry swale are summarized in **Table 10.1**.

Table 10.1. Summary of Stormwater Functions Provided by Dry Swales

Stormwater Function	Level 1 Design	Level 2 Design
Annual Runoff Volume Reduction (RR)	40%	60%
Total Phosphorus (TP) EMC Reduction[1] by BMP Treatment Process	20%	40%
Total Phosphorus (TP) Mass Load Removal	52%	76%
Total Nitrogen (TN) EMC Reduction[1] by BMP Treatment Process	25%	35%
Total Nitrogen (TN) Mass Load Removal	55%	74%
Channel Protection	Use the RRM Design Spreadsheet to calculate the Cover Number (CN) Adjustment ***OR*** Design for extra storage (optional; as needed) on the surface, in the engineered soil matrix, and in the stone/underdrain layer to accommodate a larger storm, and use NRCS TR-55 Runoff Equations [2] to compute the CN Adjustment.	
Flood Mitigation	Partial. Reduced Curve Numbers and Time of Concentration	

[1] Change in the event mean concentration (EMC) through the practice. The actual nutrient mass load removed is the product of the removal rate and the runoff reduction rate (see Table 1 in the *Introduction to the New Virginia Stormwater Design Specifications*).
[2] NRCS TR-55 Runoff Equations 2-1 thru 2-5 and Figure 2-1 can be used to compute a curve number adjustment for larger storm events, based on the retention storage provided by the practice(s).

Sources: CWP and CSN (2008), CWP, 2007

SECTION 3: DESIGN TABLE

A ***Dry Conveyance Swale*** is a linear adaptation of the bioretention basin that is aligned along a contributing impervious cover such as a roadway or parking lot. The length of the swale is generally equivalent to that of the contributing impervious area. The runoff enters the dry conveyance swale as lateral sheet flow and the total contributing drainage area cumulatively increases along the length of the swale. The treatment component of the swale can extend to a greater length for additional or storage.

A ***Dry Treatment Swale*** is located to accept runoff as concentrated flow or sheet flow from non-linear drainage areas at one or more locations and, due to site constraints or other issues, is configured as a linear practice (as opposed to a bioretention configuration). A dry treatment swale can also be used to convey stormwater from the contributing drainage area to a discharge point; however, the cumulative drainage area does not necessarily increase along the linear dimension.

Both the *Dry Conveyance Swale* and the *Dry Treatment Swale* can be configured as a Level 1 or Level 2 design (see **Table 10.2**). The difference is that the typical contributing drainage area of a *Dry Conveyance Swale* is impervious, with an adjacent grass filter strip (or other acceptable measure as described in **Section 6.4**) providing pre-treatment.

Table 10.2. Dry Swale Design Criteria

Level 1 Design (RR:40; TP:20; TN:25)	Level 2 Design (RR:60; TP:40; TN: 35)
Sizing (Sec. 5.1): Surface Area (sq. ft.) = (T_V– the volume reduced by an upstream BMP) / Storage depth [1]	Sizing (Sec. 5.1): Surface Area sq. ft.) = {(1.1)(T_v) – the volume reduced by an upstream BMP } / Storage Depth [1]
Effective swale slope ≤ 2%	Effective swale slope ≤ 1%
Media Depth: minimum = 18 inches; Recommended maximum = 36 inches	Media Depth minimum = 24 inches Recommended maximum = 36 inches
Sub-soil testing (**Section 6.2**): not needed if an underdrain is used; min. infiltration rate must be > 1/2 inch/hour to remove the underdrain requirement;	Sub-soil testing (**Section 6.2**): one per 200 linear feet of filter surface; min. infiltration rate must be > 1/2 inch/hour to remove the underdrain requirement
Underdrain (**Section 6.7**): Schedule 40 PVC with clean-outs	Underdrain and Underground Storage Layer (**Section 6.7**): Schedule 40 PVC with clean outs, and a minimum 12-inch stone sump below the invert; ***OR*** none if the soil infiltration requirements are met (see **Section 6.2**)
Media (**Section 6.6**): supplied by the vendor; tested for an acceptable phosphorus index: P-Index between 10 and 30; ***OR*** Between 7 and 23 mg/kg of P in the soil media [2]	
Inflow: sheet or concentrated flow with appropriate pre-treatment	
Pre-Treatment (**Section 6.4**): a pretreatment cell, grass filter strip, gravel diaphragm, gravel flow spreader, or another approved (manufactured) pre-treatment structure.	
On-line design	Off-line design or multiple treatment cells
Turf cover	Turf cover, with trees and shrubs
All Designs: acceptable media mix tested for phosphorus index (see **Section 6.6**)	
1 The storage depth is the sum of the Void Ratio (V_r) of the soil media and gravel layers multiplied by their respective depths, plus the surface ponding depth (Refer to **Section 6.1**) [2] Refer to Stormwater Design Specification No. 9: Bioretention for soil specifications	

Figure 10.1. Typical Dry Swale in commercial/office setting

SECTION 4: TYPICAL DETAILS

Figures 10.2 through 10.6 below provide typical schematics for dry swales.

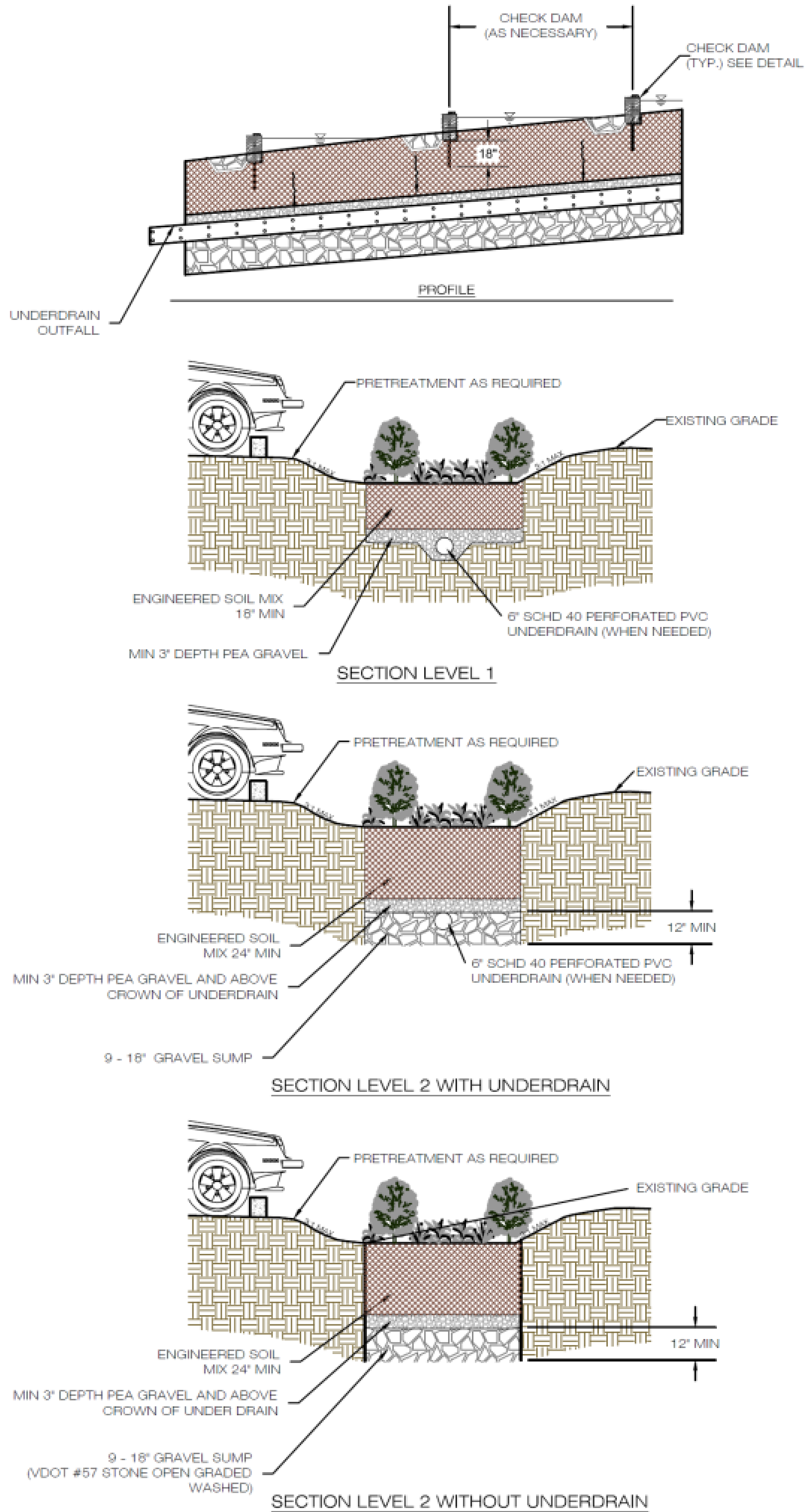
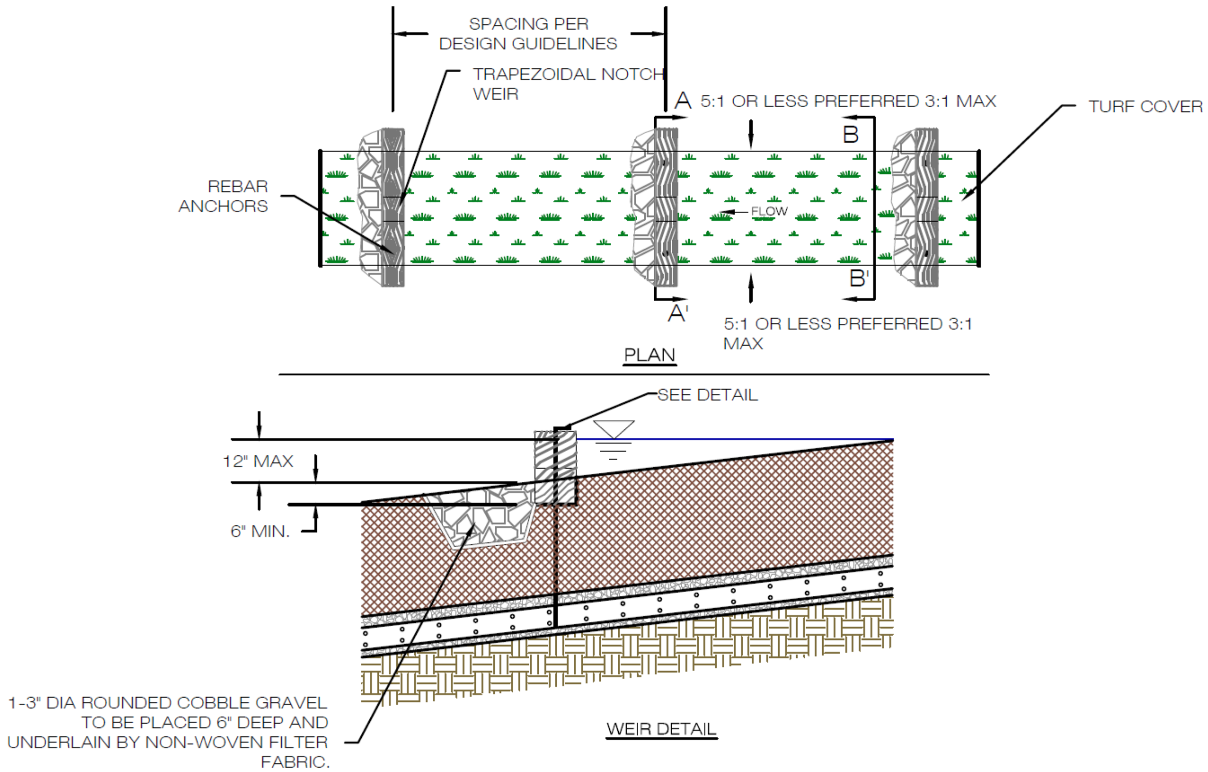
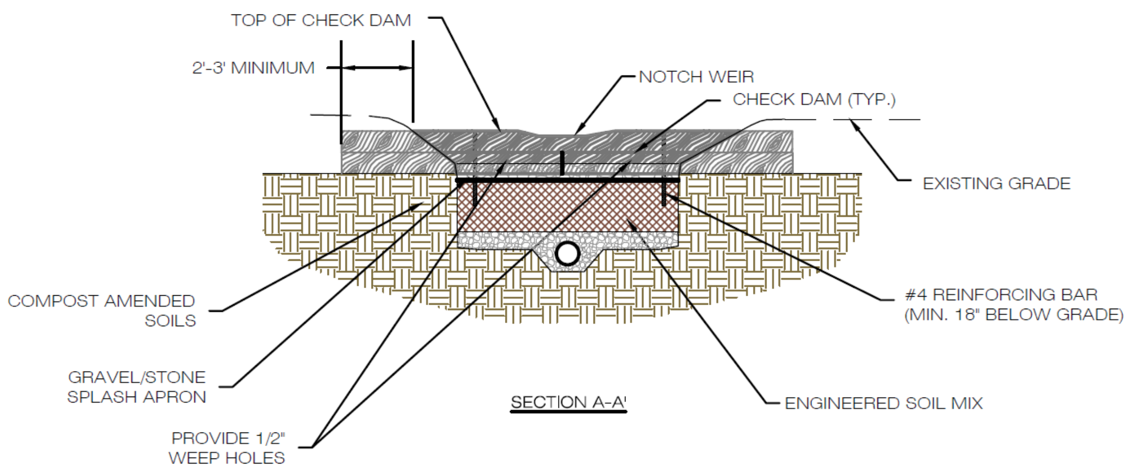


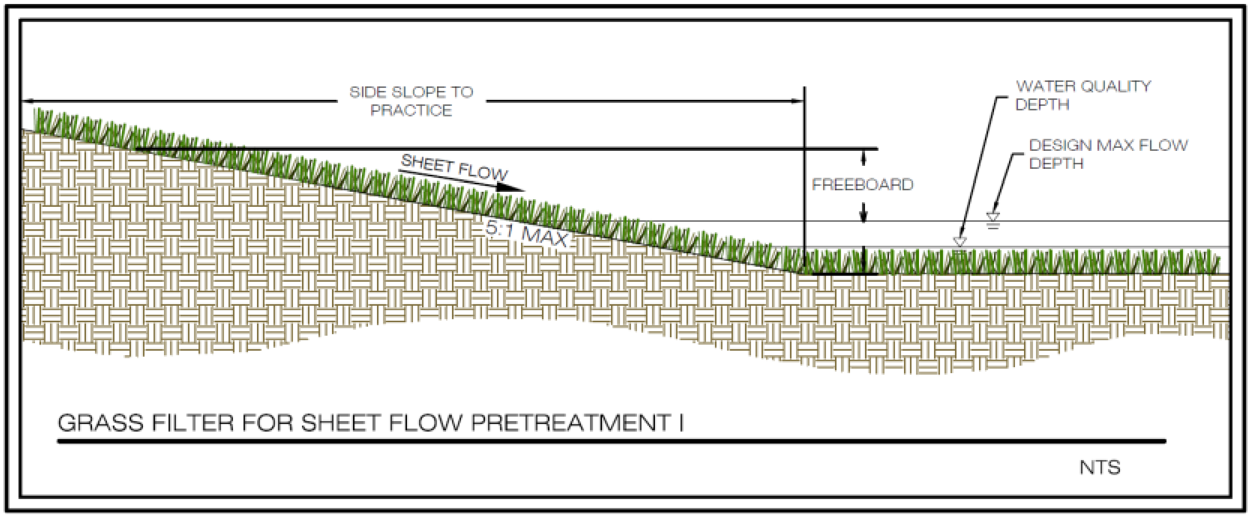
Figure 10.2. Typical Details for Level 1 and 2 Dry Swales





NOTE: CHECK DAM CONSTRUCTED OF RAILROAD TIES OR PRESSURE TREATED LOGS OR TIMBERS CHECK DAM SPANS ENTIRE WIDTH OF SWALE AND IS ANCHORED INTO THE SWALE A MINIMUM OF 2 FEET ON EACH SIDE. CHECK DAM IS KEYED INTO THE GROUND AT A 2-3 INCH DEPTH AND UNDERLAIN BY FILTER FABRIC PER STD & SPEC 3.19: RIP RAP VESCH, 1992 SMALL GRAVEL SPLASH PAD PROVIDED AT DOWNSTREAM SIDE OF CHECK DAMS

Figure 10.3. Typical Detail for Dry Swale Check Dam



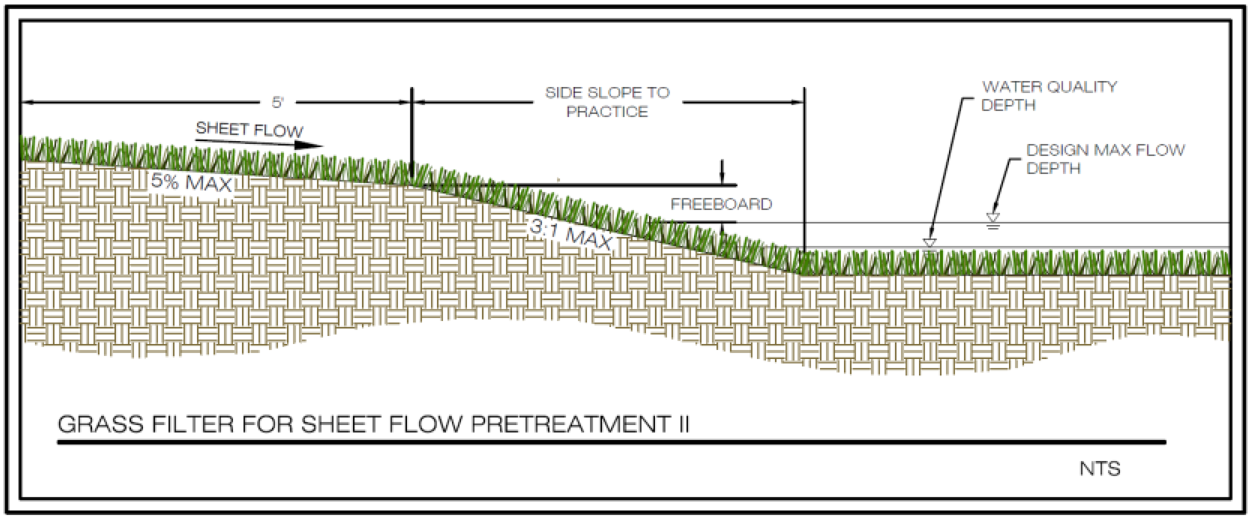


Figure 10.4: Pretreatment I and II - Grass Filter for Sheet Flow

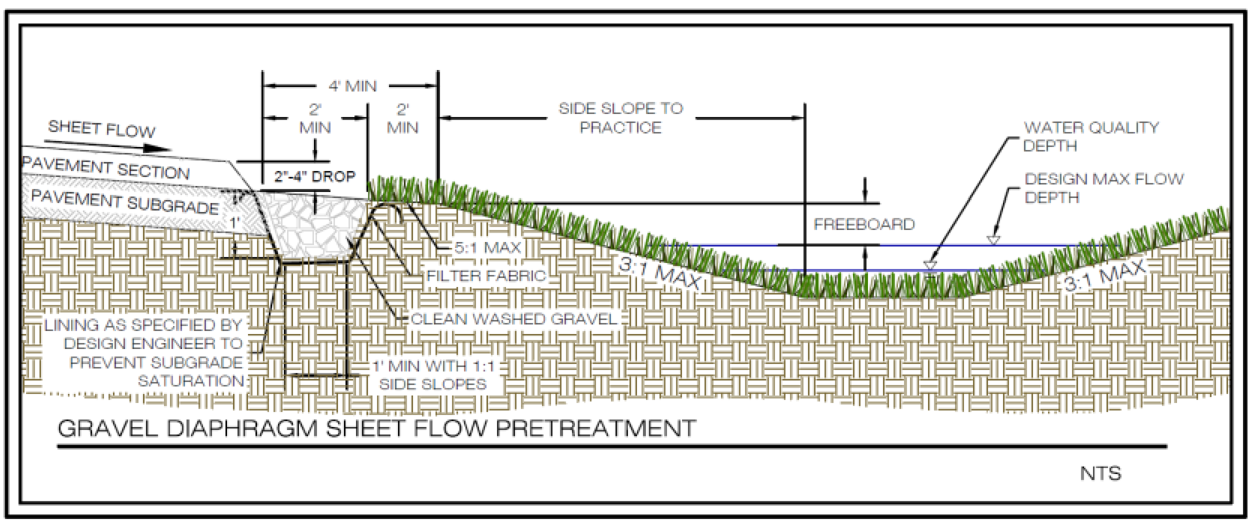


Figure 10.5: Pretreatment – Gravel Diaphragm for Sheet Flow from Impervious or Pervious

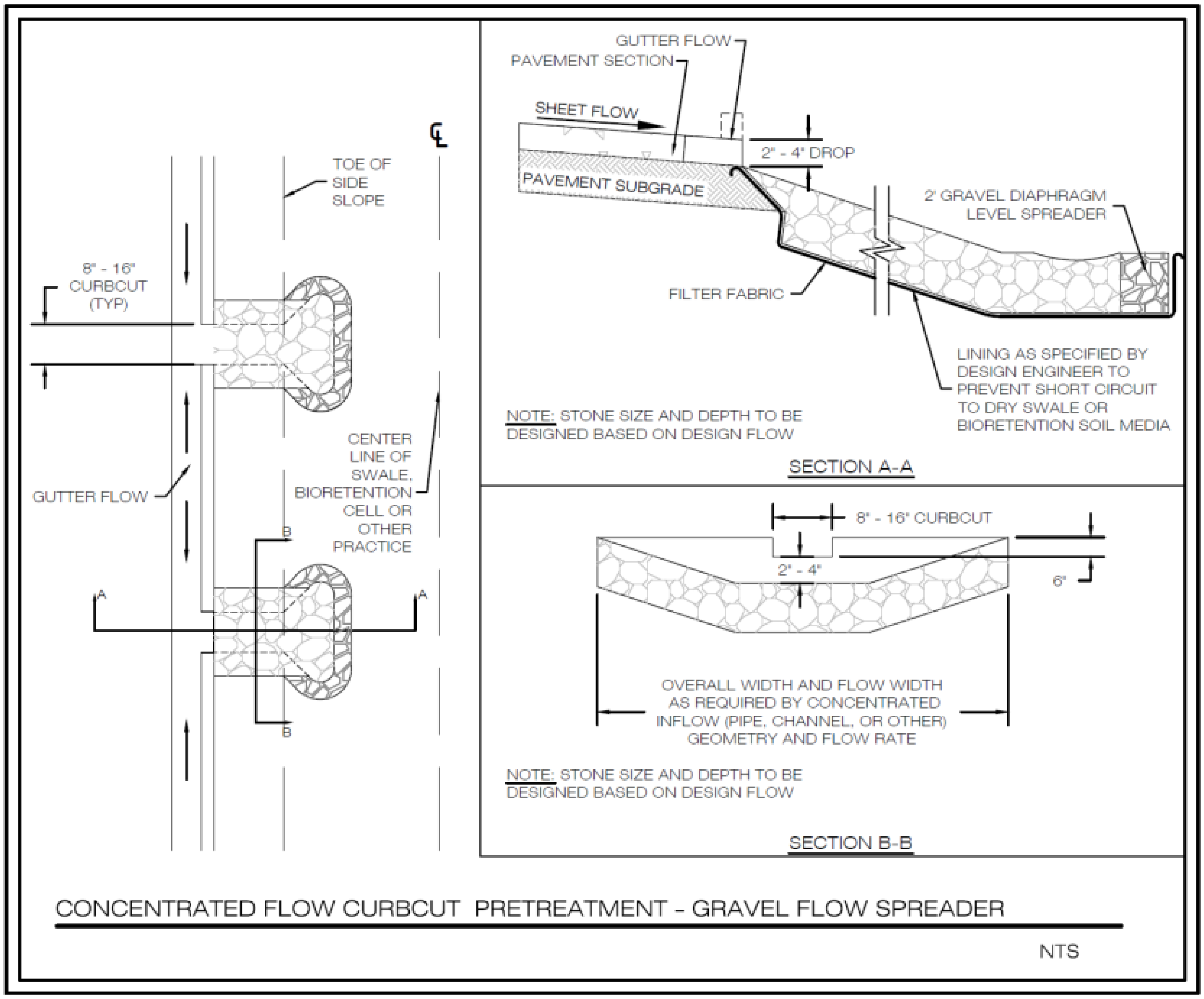


Figure 10.6: Pre-Treatment – Gravel Flow Spreader for Concentrated Flow

SECTION 5: PHYSICAL FEASIBILITY & DESIGN APPLICATIONS

Dry swales can be implemented on a variety of development sites where density and topography permit their application. Some key feasibility issues for dry swales include the following:

Contributing Drainage Area. The maximum contributing drainage area to a dry swale should be 5 acres, but preferably less. When dry swales treat larger drainage areas, the velocity of flow through the surface channel often becomes too great to treat runoff or prevent erosion in the channel. Similarly, the longitudinal flow of runoff through the soil, stone, and underdrain may cause hydraulic overloading at the downstream sections of the dry swale. An alternative is to provide a series of inlets or diversions that convey the treated water to an outlet location.

Available Space. Dry swale footprints can fit into relatively narrow corridors between utilities, roads, parking areas, or other site constraints. Dry Swales should be approximately 3% to 10% of the size of the contributing drainage area, depending on the amount of impervious cover.

Site Topography. Dry swales should be used on sites with longitudinal slopes of less than 4%, but preferably less than 2%. Check dams can be used to reduce the effective slope of the swale and lengthen the contact time to enhance filtering and/or infiltration. Steeper slopes adjacent to the swale may generate rapid runoff velocities into the swale that may carry a high sediment loading (refer to pre-treatment criteria in **Section 6.4**).

Available Hydraulic Head. A minimum amount of hydraulic head is needed to implement dry swales, measured as the elevation difference in elevation between the inflow point and the downstream storm drain invert. Dry swales typically require 3 to 5 feet of hydraulic head since they have both a filter bed and underdrain.

Hydraulic Capacity. Dry swales are an on-line practice and must be designed with enough capacity to (1) convey runoff from the 2-year and 10-year design storms at non-erosive velocities, and (2) contain the 10-year flow within the banks of the swale. This means that the swale's surface dimensions are more often determined by the need to pass the 10-year storm events, which can be a constraint in the siting of *Dry Conveyance Swales* within existing rights-of-way (e.g., constrained by sidewalks).

Depth to Water Table. Designers should ensure that the bottom of the dry swale is at least 2 feet above the seasonally high groundwater table, to ensure that groundwater does not intersect the filter bed, since this could lead to groundwater contamination or practice failure.

Soils. Soil conditions do not constrain the use of dry swales, although they normally determine whether an underdrain is needed. Low-permeability soils with an infiltration rate of less than 1/2 inch per hour, such as those classified in Hydrologic Soil Groups (HSG) C and D, will require an underdrain. Designers must verify site-specific soil permeability at the proposed location using the methods for on-site soil investigation presented in Appendix 8-A of Stormwater Design Specification No. 8 (Infiltration), in order to eliminate the requirements for an underdrain.

Utilities. Designers should consult local utility design guidance for the horizontal and vertical clearance between utilities and the swale configuration. Utilities can cross linear swales if they are specially protected (e.g., double-casing). Water and sewer lines generally need to be placed under road pavements to enable the use of dry swales.

Avoidance of Irrigation or Baseflow. Dry swales should be located to so as to avoid inputs of springs, irrigation systems, chlorinated wash-water, or other dry weather flows.

Setbacks from Building and Roads. Given their landscape position, dry swales are not subject to normal building setbacks. The bottom elevation of swales should be at least 1 foot below the invert of an adjacent road bed.

Hotspot Land Use. Runoff from hotspot land uses should not be treated with infiltrating dry swales. An impermeable liner should be used for filtration of hotspot runoff.

Community Acceptance. The main concerns of adjacent residents are perceptions that swales will create nuisance conditions or will be hard to maintain. Common concerns include the continued ability to mow grass, landscape preferences, weeds, standing water, and mosquitoes. Dry swales are actually a positive stormwater management alternative, because all these concerns can be fully addressed through the design process and proper on-going operation and routine maintenance. If dry swales are installed on private lots, homeowners will need to be educated on their routine maintenance needs, must understand the long-term maintenance plan, and may be subject to a legally binding maintenance agreement (see **Section 8**). The short ponding time of 6 hours is much less than the time required for one mosquito breeding cycle, so well-maintained dry swales should not create mosquito problems or be difficult to mow. The local government my require that dry swales be placed in a drainage or maintenance easement in order to ensure long term maintenance.

The linear nature of dry swales makes them well-suited to treat highway or low- and medium-density residential road runoff, if there is ~~an~~ adequate right-of-way width and distance between driveways. Typical applications of *Dry Conveyance Swales* include the following:

- Within a roadway right-of-way
- Along the margins of small parking lots
- Oriented from the roof (downspout discharge) to the street
- Disconnecting small impervious areas

SECTION 6: DESIGN CRITERIA

6.1. Sizing of Dry Conveyance and Dry Treatment Swales

Sizing of the surface area (SA) for Dry Swales is based on the computed Treatment Volume (T_v) of the contributing drainage area and the storage provided within the swale media and gravel layers and behind check dams. The required surface area (in square feet) is computed as the Treatment Volume (in cubic feet) divided by the equivalent storage depth (in feet). The equivalent storage depth is computed as the depth of the soil media, the gravel, and surface ponding (in feet) multiplied by the accepted void ratio.

The accepted Void Ratios (V_r) are:

Dry Swale Soil Media V_r = 0.25
Gravel V_r = 0.40
Surface Storage behind check dams V_r = 1.0

The equivalent storage depth for the Level 1 design (without considering surface ponding) is therefore computed as:

(1) $(1.5 \text{ ft.} \times 0.25) + (0.25 \text{ ft.} \times 0.40) = 0.5 \text{ ft.}$

And the equivalent storage depth for the Level 2 design (without considering surface ponding) is computed as:

(2) $(2.0 \text{ ft.} \times 0.25) + (1.0 \text{ ft.} \times 0.40) = 0.9 \text{ ft}$

The effective storage depths will vary according to the actual design depths of the soil media and gravel layer.

Note: When using Equations 3 or 4 below to calculate the required surface area of a dry swale that includes surface ponding (with check dams), the storage depth calculation (Equation 1 or 2) should be adjusted accordingly.

The Level 1 Dry Swale Surface Area (SA) is computed as:

(3) SA (sq. ft.) = { T_v – the volume reduced by an upstream BMP } / 0.5 ft.

And the Level 2 Dry Swale SA is computed as:

(4) SA (sq. ft.) = [(1.1 ∗ T_v) – the volume reduced an by upstream BMP] / 0.9 ft.

NOTE: The volume reduced by upstream Runoff Reduction BMPs is supplemented with the anticipated volume of storage created by check dams along the swale length.

Where:

SA = Minimum surface area of Dry Swale (sq. ft.)

T_v = Treatment Volume (cu. ft.) = [(1 inch)(R_v)(A)] / 12

The final Dry Swale design geometry will be determined by dividing the SA by the swale length to compute the required width; or by dividing the SA by the desired width to compute the required length.

Sizing for Stormwater Quantity

In order to accommodate a greater stormwater quantity credit for channel protection or flood control, designers may be able to create additional surface storage by expanding the surface ponding behind the check dams by either increasing the number of check dams, or by expanding the swale width at selected areas. However, the expanded surface storage footprint is limited to the ponding area directly behind the check dams and is also limited to twice the channel bottom width. Care must be taken to ensure that (1) the check dams are properly entrenched into the side slopes of the swale, and (2) adequate overflow capacity is provided over the weir.

6.2. Soil Infiltration Rate Testing

The second key sizing decision is to measure the infiltration rate of subsoils below the dry swale area to determine if an underdrain will be needed. The infiltration rate of the subsoil must exceed 1/2 inch per hour to avoid installation of an underdrain. The acceptable methods for on-site soil infiltration rate testing are outlined in Appendix 8-A of Bay-wide Stormwater Design Specification No. 8 (Infiltration). A soil test should be conducted for every 200 linear feet of dry swale.

6.3. Dry Swale Geometry

Design guidance regarding the geometry and layout of dry swales is provided below.

Shape. A parabolic shape is preferred for dry swales for aesthetic, maintenance and hydraulic reasons. However, the design may be simplified with a trapezoidal cross-section, as long as the soil filter bed boundaries lay in the flat bottom areas.

Side Slopes. The side slopes of dry swales should be no steeper than 3H:1V for maintenance considerations (i.e., mowing). Flatter slopes are encouraged where adequate space is available, to enhance pre-treatment of sheet flows entering the swale. Swales should have a bottom width of from 4 to 8 feet to ensure that an adequate surface area exists along the bottom of the swale for filtering. If a swale will be wider than 8 feet, the designer should incorporate berms, check dams, level spreaders or multi-level cross-sections to prevent braiding and erosion of the swale bottom.

Swale Longitudinal Slope. The longitudinal slope of the swale should be moderately flat to permit the temporary ponding of the Treatment Volume within the channel. The recommended swale slope is less than or equal to 2% for a Level 1 design and less than or equal to 1% for a Level 2 design, though slopes up to 4% are acceptable if check dams are used. A Dry Swale designed with a longitudinal slope less than 1% may be restricted by the locality. The minimum recommended slope for an on-line Dry Swale is 0.5%. An off-line dry swale may be designed with a longitudinal slope of less than 0.5% and function similar to a bioretention practice, although this option may be limited by the locality. Refer to **Table 10.3** for check dam spacing based on the swale longitudinal slope.

Table 10.3. Typical Check Dam (CD) Spacing to Achieve Effective Swale Slope

Swale Longitudinal Slope	LEVEL 1	LEVEL 2		
	Spacing [1] of 12-inch High (max.) Check Dams [3, 4] to Create an Effective Slope of 2%	Spacing [1] of 12-inch High (max.) Check Dams [3, 4] to Create an Effective Slope of 0	to	1%
0.5%	–	200 ft.	to	–
1.0%	–	100 ft.	to	–
1.5%	–	67 ft.	to	200 ft.
2.0%	–	50 ft.	to	100 ft.
2.5%	200 ft.	40 ft.	to	67 ft.
3.0%	100 ft.	33 ft.	to	50 ft.
3.5%	67 ft.	30 ft.	to	40 ft.
4.0%	50 ft.	25 ft.	to	33 ft.
4.5% [2]	40 ft.	20 ft.	to	30 ft.
5.0% [2]	40 ft.	20 ft.	to	30 ft.

Notes:
[1] The spacing dimension is half of the above distances if a 6-inch check dam is used.
[2] *Dry Conveyance Swales* and *Treatment Swales* with slopes greater than 4% require special design considerations, such as drop structures to accommodate greater than 12-inch high check dams (and therefore a flatter effective slope), in order to ensure non-erosive flows.
[3] A Check dams requires a stone energy dissipater at its downstream toe.
[4] Check dams require weep holes at the channel invert. Swales with slopes less than 2% will require multiple weep holes (at least 3) in each check dam.

Check dams. Check dams must be firmly anchored into the side-slopes to prevent outflanking and be stable during the 10 year storm design event. The height of the check dam relative to the normal channel elevation should not exceed 12 inches. Each check dam should have a minimum of one weep hole or a similar drainage feature so it can dewater after storms. Armoring may be needed behind the check dam to prevent erosion. The check dam must be designed to spread runoff evenly over the Dry Swale's filter bed surface, through a centrally located depressed with a length equal to the filter bed width. In the center of the check dam, the depressed weir length should be checked for the depth of flow, sized for the appropriate design storm (see **Figure 10.3**). Check dams should be constructed of wood or stone.

Soil Plugs. Soil plugs serve to help minimize the potential for blow-out of the soil media underneath the check dams, due to hydrostatic pressure from the upstream ponding. Soil plugs are appropriate for Dry Swales (1) on slopes of 4% or greater, or (2) with 12-inch high check dams.

Ponding Depth. Drop structures or check dams can be used to create ponding cells along the length of the swale. The maximum ponding depth in a swale should not exceed 12 inches at the most downstream point.

Drawdown. Dry swales should be designed so that the desired Treatment Volume is completely filtered within 6 hours or less. This drawdown time can be achieved by using the soil media mix specified in **Section 6.6** and an underdrain along the bottom of the swale, or native soils with adequate permeability, as verified through testing (see **Section 6.2**).

Underdrain. Underdrains are provided in dry swales to ensure that they drain properly after storms. The underdrain should have a minimum diameter of 6 inches and be encased in a 12-inch deep gravel bed. Two layers of stone should be used. A choker stone layer, consisting of #8 or #78 stone at least 3 inches deep, should be installed immediately below the filter media. Below the choker stone layer, the main underdrain layer should be at least 12 inches deep and composed on 1-inch double washed stone. The underdrain pipe should be set at least 4 inches above the bottom of the stone layer.

6.4. Pre-treatment

Pre-treatment for a *Dry Conveyance Swale* is in the form of a grass filter strip (minimum 10 ft. wide) along the length of the contributing impervious cover. Pre-treatment for a *Dry Treatment Swale* is required at the inflow points along the length of the Dry Swale, to trap coarse sediment particles before they reach the filter bed to prevent premature clogging. Several pre-treatment measures are feasible, depending on whether the specific location in the Dry Swale system will be receiving sheet flow, shallow concentrated flow, or fully concentrated flow:

- ***Initial Sediment Forebay*** (channel flow). This grass cell is located at the upper end of the dry swale segment with a 2:1 length to width ratio and a storage volume equivalent to at least 15% of the total Treatment Volume.
- ***Check dams*** (channel flow). These energy dissipation devices are acceptable as pre-treatment on small swales with drainage areas of less than 1 acre.
- ***Tree Check dams*** (channel flow). These are street tree mounds that are placed within the bottom of a Dry Swale up to an elevation of 9 to 12 inches above the channel invert. One side has a gravel or river stone bypass to allow storm runoff to percolate through.
- ***Grass Filter Strip*** (sheet flow). Grass filter strips extend from the edge of the pavement to the bottom of the dry swale at a 5:1 slope or flatter. Alternatively, provide a combined 5 feet of grass filter strip at a maximum 5% (20:1) slope and 3:1 or flatter side slopes on the dry swale. (**See Figure 10.4**)
- ***Gravel Diaphragm*** (sheet flow). A gravel diaphragm located at the edge of the pavement should be oriented perpendicular to the flow path to pre-treat lateral runoff, with a 2 to 4 inch drop. The stone must be sized according to the expected rate of discharge. (**See Figure 10.5**)
- ***Pea Gravel Flow Spreader*** (concentrated flow). The gravel flow spreader is located at curb cuts, downspouts, or other concentrated inflow points, and should have a 2 to 4 inch elevation drop from a hard-edged surface into a gravel or stone diaphragm. The gravel should extend the entire width of the opening and create a level stone weir at the bottom or treatment elevation of the swale. (**See Figure 10.6**)

6.5. Conveyance and Overflow

The bottom width and slope of a Dry Swale should be designed such that ~~a~~ the velocity of flow from a 1-inch rainfall will not exceed 3 feet per second. Check dams may be used to achieve the needed runoff reduction volume, as well as to reduce the flow velocity (refer to Stormwater Design Specification No. 3: Grass Swale, for additional guidance on channel design). Check dams should be spaced based on channel slope and ponding requirements, consistent with the criteria in **Table 10.3**.

The swale should also convey the locally required design storms (usually the 2- and 10-year storms) at non-erosive velocities with at least 3 inches of freeboard. The analysis should evaluate the flow profile through the channel at normal depth, as well as the flow depth over top of the check dams. Refer to Stormwater Design Specifcation No. 3: Grass Channels, for design criteria pertaining to maximum velocities and depth of flow.

A Dry Swales may be designed as an off-line system, with a flow splitter or diversion to divert runoff in excess of the design capacity to an adjacent conveyance system. Or, strategically placed overflow inlets may be placed along the length of the swale to periodically pick up water and reduce the hydraulic loading at the downstream limits.

6.6. Filter Media

Dry Swales require replacement of native soils with a prepared soil media. The soil media provides adequate drainage, supports plant growth, and facilitates pollutant removal within the Dry Swale. At least 18 inches of soil media should be added above the choker stone layer to create an acceptable filter. The recipe for the soil media is identical to that used for bioretention and is provided in **Table 10.4** below (refer to Stormwater Design Specification No. 9: Bioretention, for additional soil media specifications). The soil media should be obtained from an approved vendor to create a consistent, homogeneous fill media. One design adaptation is to use 100% sand for the first 18 inches of the filter and add a combination of topsoil and leaf compost for the top 4 inches, where turf cover will be maintained.

6.7. Underdrain and Underground Storage Layer

Some Level 2 Dry Swale designs will not use an underdrain (where soil infiltration rates meet minimum standards (see **Section 6.2** and the design table in **Section 3**). For Level 2 designs with an underdrain, an underground storage layer, consisting of a minimum 12 inches of stone, should be incorporated below the invert of the underdrain. The depth of the storage layer will depend on the target treatment and storage volumes needed to meet water quality, channel protection, and/or flood protection criteria. However, the bottom of the storage layer must be at least 2 feet above the seasonally high groundwater table. The storage layer should consist of clean, washed #57 stone or an approved infiltration module.

A Dry Swale should include observation wells with cleanout pipes along the length of the swale, if the contributing drainage area exceeds 1 acre. The wells should be tied into any T's or Y's in the underdrain system, and should extend upwards to be flush with surface, with a vented cap.

6.8. Landscaping and Planting Plan

Designers should choose grasses, herbaceous plants, or trees that can withstand both wet and dry periods and relatively high velocity flows for planting within the channel. Salt tolerant grass species should be chosen for Dry Swales located along roads. Taller and denser grasses are preferable, although the species is less important than good stabilization and dense vegetative cover. Grass species should have the following characteristics: a deep root system to resist scouring; a high stem density with well-branched top growth; water-tolerance; resistance to being flattened by runoff; and an ability to recover growth following inundation. To find a list of plant species suitable for use in Dry Swales, consult the Virginia Erosion and Sediment Control Handbook.

6.9. Dry Swale Material Specifications

Table 10.4 outlines the standard material specifications for constructing Dry Swales**.**

Table 10.4. Dry Swale Material Specifications

Material	Specification	Notes
Filter Media Composition	Filter Media to contain: • 85-88% sand • 8-12% soil fines • 3-5% organic matter in form of leaf compost	The volume of filter media is based on 110% of the product of the surface area and the media depth, to account for settling.
Filter Media Testing	P-Index range = 10-30; Cation Exchange Capacity (CEC) greater than 10. Mix on-site or procure from an approved media vendor (refer to Stormwater Design Spec No. 9: Bioretention, for additional soil media information.	
Surface Cover	Turf or river stone.	
Top Soil	4 inch surface depth of loamy sand or sandy loam texture, with less than 5% clay content, a corrected pH of 6 to 7, and at least 2% organic matter.	
Filter Fabric	A non-woven polyprene geotextile with a flow rate of > 110 gal./min./sq. ft. (e.g., Geotex 351 or equivalent); Apply immediately above the underdrain only.] For hotspots and certain karst sites only, use an appropriate liner on the bottom.	
Choking Layer	A 2 to 4 inch layer of sand over a 2 inch layer of choker stone (typically #8 or # 89 washed gravel) laid above the underdrain stone.	
Stone and/or Storage Layer	A 9 to 18 inch layer (depending on the desired depth of the storage layer) of # 57 stone should be double-washed and clean and free of all soil and fines.	
Underdrains, Cleanouts, and Observation Wells	6-inch rigid schedule 40 PVC pipe, with 3/8-inch perforations. Use Corrugated HDPE for Rain Gardens.	Install perforated pipe for the full length of the Dry Swale cell. Use non-perforated pipe, as needed, to connect with the storm drain system.
Vegetation	Plant species as as specified on the landscaping plan	
Check Dams	Use non-erosive material such as wood, gabions, riprap, or concrete. All check dams should be underlain with filter fabric, and include weep holes. Wood used for check dams should consist of pressure-treated logs or timbers, or water-resistant tree species such as cedar, hemlock, swamp oak or locust.	
Erosion Control Fabric	Where flow velocities dictate, use woven biodegradable erosion control fabric or mats (EC2) that are durable enough to last at least 2 growing seasons.	

SECTION 7: REGIONAL AND SPECIAL CASE DESIGN ADAPTATIONS

7.1. Karst Terrain

Shallow Dry Swales are an acceptable practice in the karst regions of the Ridge and Valley province. To prevent sinkhole formation and possible groundwater contamination, Dry Swales should use impermeable liners and underdrains. Therefore, Level 2 Dry Swale designs that rely on infiltration are not recommended in any area with a moderate or high risk of sinkhole formation (Hyland, 2005).

If a dry swale facility is located in an area of sinkhole formation, standard setbacks to buildings should be increased.

7.2. Coastal Plain

The flat terrain, low head and high water table of many coastal plain sites can constrain the application of Dry Swales (particularly Level 2 designs). Swales perform poorly in extremely flat terrain because they lack enough grade to create storage cells, and they lack sufficient hydraulic head to drive the system. In these situations, the following design adaptations apply:

- The minimum depth to the seasonally high groundwater table can be 1 foot, as long as the Dry Swale is equipped with an underdrain.
- A minimum underdrain slope of 0.5% must be maintained to ensure positive drainage.
- The underdrain should be tied into the drainage ditch system.

While these design criteria permit Dry Swales to be used on a wider range of coastal plain sites, it is important to avoid installing Dry Swales on marginal sites. Other stormwater practices, such as Wet Swales, ditch wetland restoration, and smaller linear wetlands are preferred alternatives for coastal plain sites.

7.3. Steep Terrain

In areas of steep terrain, Dry Swales can be implemented with contributing slopes of up to 20% gradient, as long as a multiple cell design is used to dissipate erosive energy prior to filtering. This can be accomplished by terracing a series of Dry Swale cells to manage runoff across or down a slope. The drop in elevation between cells should be limited to 1 foot and armored with river stone or a suitable equivalent. A greater emphasis on properly engineered energy dissipaters and/or drop structures is warranted.

7.4. Cold Climate and Winter Performance

Dry swales can store snow and treat snowmelt runoff when they serve road or parking lot drainage. If roadway salt is applied within the CDA, Dry Swales should be planted with salt-tolerant non-woody plant species. Consult the Minnesota Stormwater Manual for a list of salt-tolerant grass species (MSSC, 2005). The underdrain pipe should also extend below the frost line and be oversized by one pipe size to reduce the chances of freezing.

7.5. Linear Highway Sites

Dry swales are a preferred stormwater practice for linear highway sites.

SECTION 8: CONSTRUCTION

8.1. Construction Sequence

Construction Stage ESC Controls. Dry Swales should be fully protected by silt fence or construction fencing, particularly if they will provide an infiltration function (i.e., have no underdrains). Ideally, Dry Swale areas should remain *outside* the limits of disturbance during construction to prevent soil compaction by heavy equipment.

Dry swale locations may be used for small sediment traps or basins during construction. However, these must be accompanied by notes and graphic details on the E&S Control plan specifying that the maximum excavation depth of the sediment trap/basin at the construction stage must (1) be at least 1 foot above the depth of the post-construction Dry Swale installation, (2) contain an underdrain, and (3) specify the use of proper procedures for conversion from a temporary practice to a permanent one, including de-watering, cleanout and stabilization.

8.2. Construction Sequence

The following is a typical construction sequence to properly install a Dry Swale, although the steps may be modified to adapt to different site conditions.

Step 1: Protection during Site Construction. As noted above, Dry Swales should remain outside the limit of disturbance during construction to prevent soil compaction by heavy equipment. However, this is seldom practical given that swales are a key part of the drainage system at most sites. In these cases, temporary E&S controls such as dikes, silt fences and other similar measures should be integrated into the swale design throughout the construction sequence. Specifically, barriers should be installed at key check dam locations, erosion control fabric should be used to protect the channel, and excavation should be no deeper than 2 feet above the proposed invert of the bottom of the planned underdrain. Dry Swales that lack underdrains (and rely on filtration) must be fully protected by silt fence or construction fencing to prevent compaction by heavy equipment during construction.

Step 2. Installation may only begin after the entire contributing drainage area has been stabilized by vegetation. The designer should check the boundaries of the contributing drainage area to ensure it conforms to original design. Additional E&S controls may be needed during swale construction, particularly to divert stormwater from the Dry Swale until the filter bed and side slopes are fully stabilized. Pre-treatment cells should be excavated first to trap sediments before they reach the planned filter beds.

Step 3. Excavators or backhoes should work from the sides to excavate the Dry Swale area to the appropriate design depth and dimensions. Excavating equipment should have scoops with adequate reach so they do not have to sit inside the footprint of the Dry Swale area.

Step 4. The bottom of the Dry Swale should be ripped, roto-tilled or otherwise scarified to promote greater infiltration.

Step 5. Place an acceptable filter fabric on the underground (excavated) sides of the dry swale with a minimum 6 inch overlap. Place the stone needed for storage layer over the filter bed. Perforate the underdrain pipe and check its slope. Add the remaining stone jacket, and then pack #57 stone to 3 inches above the top of the underdrain, and then add 3 inches of pea gravel as a filter layer.

Step 6. Add the soil media in 12-inch lifts until the desired top elevation of the Dry Swale is achieved. Wait a few days to check for settlement, and add additional media as needed.

Step 7. Install check dams, driveway culverts and internal pre-treatment features, as specified in the plan.

Step 8. Prepare planting holes for specified trees and shrubs, install erosion control fabric where needed, spread seed or lay sod, and install any temporary irrigation.

Step 9. Plant landscaping materials as shown in the landscaping plan, and water them weekly during the first 2 months. The construction contract should include a care and replacement warranty to ensure that vegetation is properly established and survives during the first growing season following construction.

Step 10. Conduct a final construction inspection and develop a punchlist for facility acceptance.

8.3. Construction Inspection

Inspections are needed during construction to ensure that the Dry Swale practice is built in accordance with these specifications. Detailed inspection checklists should be used that include sign-offs by qualified individuals at critical stages of construction, to ensure that the contractor's interpretation of the plan is consistent with the designer's intent. An example construction phase inspection checklist for Dry Swales can be accessed at the CWP website at:

http://www.cwp.org/Resource_Library/Controlling_Runoff_and_Discharges/sm.htm
(scroll to Tool6: Plan Review, BMP Construction, and Maintenance Checklists)

Some common pitfalls can be avoided by careful construction supervision that focuses on the following key aspects of dry swale installation.

- Check the filter media to confirm that it meets specifications and is installed to the correct depth.
- Check elevations such as the invert of the underdrain, inverts for the inflow and outflow points, and the ponding depth provided between the surface of the filter bed and the overflow structure.
- Ensure that caps are placed on the upstream (but not the downstream) ends of the underdrains.

- Make sure the desired coverage of turf or erosion control fabric has been achieved following construction, both on the filter beds and their contributing side-slopes.
- Inspect check dams and pre-treatment structures to make sure they are properly installed and working effectively.
- Check that outfall protection/energy dissipation measures at concentrated inflow and outflow points are stable.

The real test of a Dry Swale occurs after its first big storm. The post-storm inspection should focus on whether the desired sheetflow, shallow concentrated flows or fully concentrated flows assumed in the plan actually occur in the field. Also, inspectors should check that the Dry Swale drains completely within minimum 6 hour drawdown period. Minor adjustments are normally needed as a result of this post-storm inspection (e.g., spot reseeding, gully repair, added armoring at inlets or outfalls, and check dam realignment.

SECTION 9: MAINTENANCE

9.1. Maintenance Agreements

Section 4 VAC 50-60-124 of the regulations specifies the circumstances under which a maintenance agreement must be executed between the owner and the local program. This section sets forth inspection requirements, compliance procedures if maintenance is neglected, notification of the local program upon transfer of ownership, and right-of-entry for local program personnel.

If a Dry Swale is located on a residential lot, the existence and purpose of the Dry Swale must be noted on the deed of record. Homeowners will need to be provided a simple document that explains their purpose and routine maintenance needs. A deed restriction, drainage easement or other mechanism enforceable by the qualifying local program must be in place to help ensure that dry swales are maintained. The mechanism should, if possible, grant authority for local agencies to access the property for inspection or corrective action. In addition, the GPS coordinates should be logged for all Dry Swales, upon facility acceptance, and submitted for entry into the local BMP maintenance tracking database.

9.2. Maintenance Inspections

Annual inspections are used to trigger maintenance operations such as sediment removal, spot revegetation and inlet stabilization. The following is a list of several key maintenance inspection points:

- Add reinforcement planting to maintain 95% turf cover or vegetation density. Reseed any salt-killed vegetation.
- Remove any accumulated sand or sediment deposits on the filter bed surface or in pre-treatment cells.
- Inspect upstream and downstream of check dams for evidence of undercutting or erosion, and remove trash or blockages at weepholes.
- Examine filter beds for evidence of braiding, erosion, excessive ponding or dead grass.

- Check inflow points for clogging, and remove any sediment.
- Inspect side slopes and grass filter strips for evidence of any rill or gully erosion, and repair as needed.
- Look for any bare soil or sediment sources in the contributing drainage area, and stabilize immediately.

Ideally, inspections should be conducted in the spring of each year. Example maintenance inspection checklists for Dry Swales can be accessed in Appendix C of Chapter 9 of the *Virginia Stormwater Management Handbook* (2010) or at CWP website at:

http://www.cwp.org/Resource_Library/Controlling_Runoff_and_Discharges/sm.htm
(scroll to Tool6: Plan Review, BMP Construction, and Maintenance Checklists)

9.3 Routine Maintenance and Operation

Once established, Dry Swales have minimal maintenance needs outside of the spring clean up, regular mowing, and pruning and management of trees and shrubs. The surface of the filter bed can become clogged with fine sediment over time, but this can be alleviated through core aeration or deep tilling of the filter bed. Additional effort may be needed to repair check dams, stabilize inlet points, and remove deposited sediment from pre-treatment cells.

SECTION 10: REFERENCES

Claytor, R. and T. Schueler. 1996. *Design of Stormwater Filtering Systems*. Center for Watershed Protection. Ellicott City, MD.

Center for Watershed Protection (CWP). 2007. *National Pollutant Removal Performance Database Version 3.0*. Center for Watershed Protection, Ellicott City, MD.

Hirschman, D. and J. Kosco. 2008. *Managing Stormwater in Your Community: A Guide for Building an Effective Post-Construction Program*. EPA Publication 833-R-08-001, Tetra-Tech, Inc. and the Center for Watershed Protection. Ellicott City, MD.

Maryland Department of Environment (MDE). 2000. *Maryland Stormwater Design Manual*. Baltimore, MD. Available online at:
http://www.mde.state.md.us/Programs/WaterPrograms/SedimentandStormwater/stormwater_design/index.asp

Schueler, T., D. Hirschman, M. Novotney and J. Zielinski. 2007. *Urban stormwater retrofit practices*. Manual 3 in the Urban Subwatershed Restoration Manual Series. Center for Watershed Protection, Ellicott City, MD.

Schueler, T. 2008. Technical Support for the Baywide Runoff Reduction Method. Chesapeake Stormwater Network. Baltimore, MD. www.chesapeakestormwater.net

Virginia Stormwater Management Handbook. 1999. *Volumes 1 and 2*. Richmond, VA.

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 11

WET SWALE

VERSION 1.9
March 1, 2011

SECTION 1: DESCRIPTION

Wet swales can provide runoff filtering and treatment within the conveyance system and are a cross between a wetland and a swale. These linear wetland cells often intercept shallow groundwater to maintain a wetland plant community. The saturated soil and wetland vegetation provide an ideal environment for gravitational settling, biological uptake, and microbial activity. On-line or off-line cells are formed within the channel to create saturated soil or shallow standing water conditions (typically less than 6 inches deep).

SECTION 2: PERFORMANCE

While Wet Swales do not provide runoff volume reduction, they do provide moderate pollutant removal, depending on their design (see **Table 11.1**). Wet Swales are particularly well suited for the flat terrain and high water table of the coastal plain.

Table 11.1. Summary of Stormwater Functions Provided by Wet Swales

Stormwater Function	Level 1 Design	Level 2 Design
Annual Runoff Volume Reduction (RR)	0%	0%
Total Phosphorus (TP) EMC Reduction[1] by BMP Treatment Process	20%	40%
Total Phosphorus (TP) Mass Load Removal	20%	40%
Total Nitrogen (TN) EMC Reduction[1] by BMP Treatment Process	25%	35%
Total Nitrogen (TN) Mass Load Removal	25%	35%
Channel Protection	Limited – reduced Time of Concentration (TOC); and partial Channel Protection Volume (CPv) can be provided above the Treatment Volume (T_V), within the allowable maximum ponding depth.	
Flood Mitigation	Limited – reduced TOC	
[1] Change in event mean concentration (EMC) through the practice.		

Sources: CWP and CSN (2008), CWP, 2007

SECTION 3: DESIGN TABLE

The major design goal for Wet Swales is to maximize nutrient removal. To this end, designers may choose the baseline design (Level 1) or an enhanced design (Level 2) that maximizes nutrient removal.

Table 11.2. Wet Swale Design Criteria

Level 1 Design (RR:0; TP:20; TN:25)	Level 2 Design (RR:0; TP:40; TN:35)
T_V = [(1 inch)(R_V)(A)] / 12 – the volume reduced by an upstream RR BMP	T_V = [(1.25 inch)(R_V)(A)] / 12 – the volume reduced by an upstream RR BMP
Swale slopes less than 2% [1]	Swale slopes less than 1% [1]
On-line design	Off-line swale cells
No planting	Wetland planting within swale cells
Turf cover in buffer	Trees within swale cells
[1] Wet Swales are generally recommended only for flat coastal plain conditions with a high water table. A linear wetland is always preferred to a wet swale. However, check dams or other design features that lower the effective longitudinal grade of the swale can by applied on steeper sites, to comply with these criteria.	

SECTION 4: TYPICAL DETAILS

Figure 11.1 provides a standard plan and profile detail for an on-line Wet Swale with an off-line wetland cell. **Figure 11.2** shows a typical plan, profile, and section for a Wet Swale.

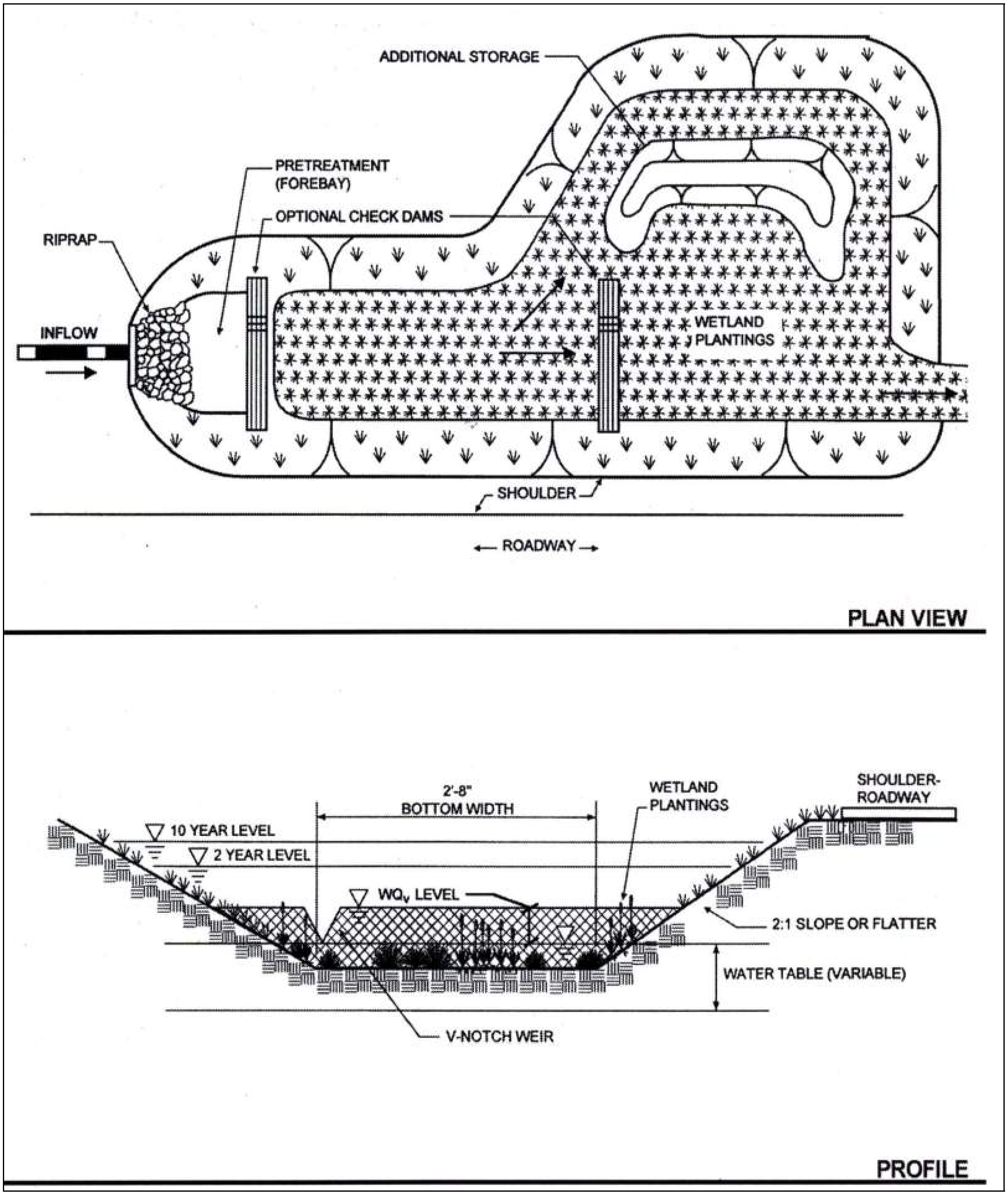


Figure 11.1. Wet Swale Details

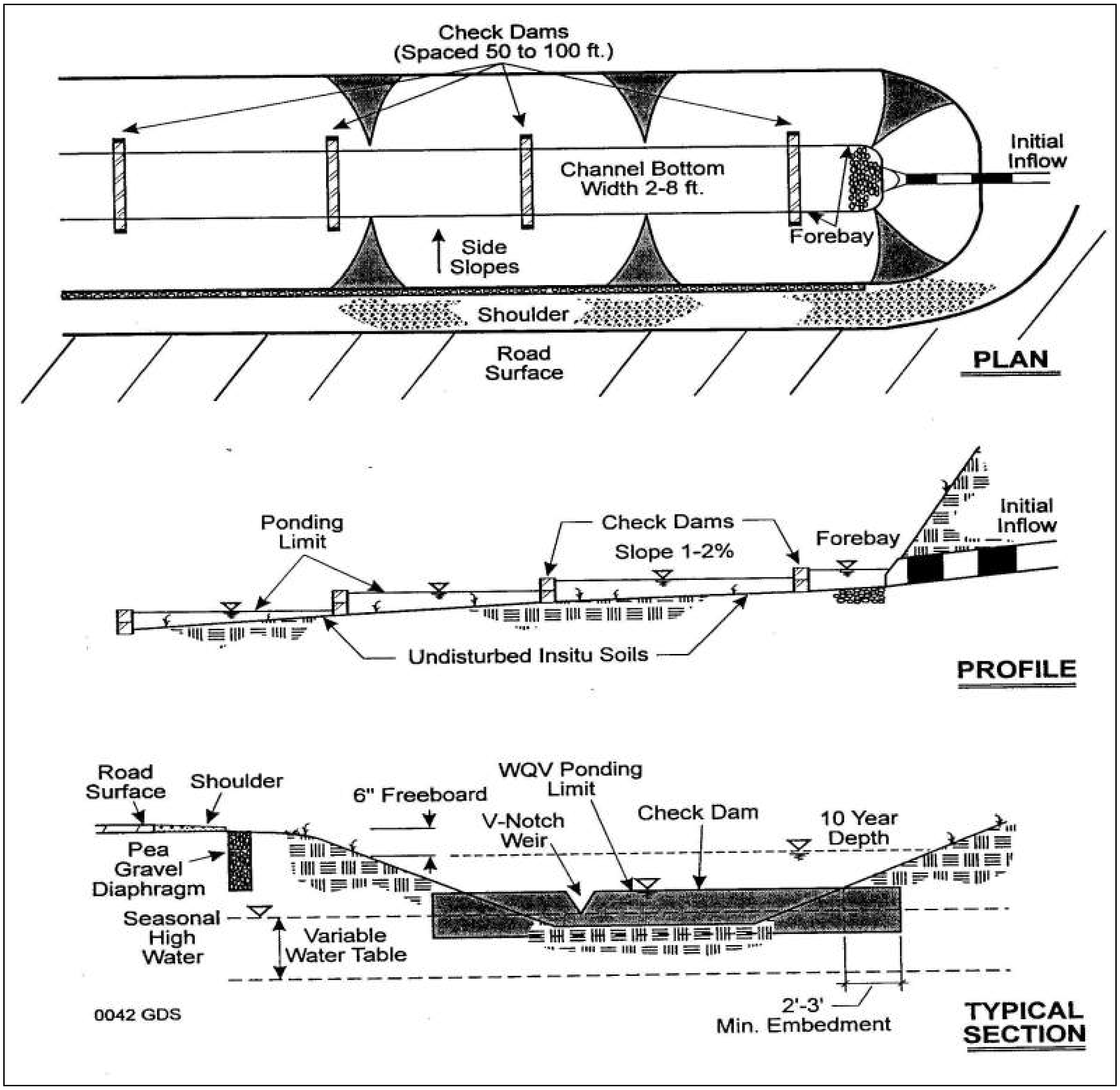


Figure 11.2. Typical Wet Swale Schematics

SECTION 5: PHYSICAL FEASIBILITY & DESIGN APPLICATIONS

Wet swales can be implemented on development sites where development density, topography, and soils are consistent with the following criteria.

Contributing Drainage Area. The maximum contributing drainage area (CDA) to a Wet Swale should not exceed 5 acres, but preferably will be less.

Space Required. Wet Swale footprints usually cover about 5% to 15% of their contributing drainage area.

Site Topography. Site topography constrains Wet Swales; some gradient is needed to provide water quality treatment, but not so much that treatment is impeded. Wet swales generally work best on sites with relatively flat slopes (i.e., less than 2% gradient).

A modification of the wet swale is the Regenerative Conveyance System (RCS). The RCS can be used to bring stormwater down steeper grades through a series of step pools. Refer to Section 7: Regional and Special Case Design Adaptations.

Depth to Water Table. It *is* permissible for wet swales to intersect the water table.

Soils. Wet Swales work best on the more impermeable Hydrologic Soil Group (HSG) C or D soils.

Hydraulic Capacity. When a Wet Swale is used as an on-line practice (Level 1 design), it must be designed with enough capacity to convey runoff from the 10-year design storm and be non-erosive during both the 2-year and 10-year design storms. This means that the surface dimensions are largely determined by the need to pass these larger storm events.

When a Wet Swales is used as an off-line practice (Level 2 design), a bypass or diversion structure must be designed to divert the large storm (e.g., when the flow rate and/or volume xceeds the water quality Treatment Volume) to an adequate channel or conveyance system. The Wet Swale is then designed to provide the required volume and meet the velocity and residence time criteria for the T_v.

Hotspot Land Uses. Wet Swales are not recommended to treat stormwater hotspots, due to the potential interaction with the water table and the risk that hydrocarbons, trace metals, and other toxic pollutants could migrate into the groundwater. For a list of designated stormwater hotspots, consult Stormwater Design Specification No. 8 (Infiltration).

Highway Runoff. The linear nature of Wet Swales makes them well suited to treat highway or low- and medium-density residential road runoff, if there is adequate right-of-way width and distance between driveways.

SECTION 6: DESIGN CRITERIA

6.1. Sizing of Wet Swales

Wet Swales should be designed to capture and treat the Treatment Volume (T_v) remaining from the upstream runoff reduction practices. Runoff treatment credit can be taken for any temporary or permanent storage created within each Wet Swale cell. This includes the permanent wet storage below the normal pool level and up to 12 inches of temporary storage created by check dams or other design features. Designers must also demonstrate that *on-line* Wet Swales have sufficient capacity to safely convey the 10-year design storm event. Refer to the hydraulic design methods outlined in Stormwater Design Specification No. 3 (Grass Channels). (NOTE: After the new Virginia Stormwater Management Regulation revisions take effect, the above requirement will be driven by the SWM Regulations (4 VAC 50-60-66 A 1 and B 1), which will supersede the MS-19 criteria of the Virginia E&S Control Regulations.)

6.2. Swale Pretreatment and Geometry

The Wet Swale should follow the general design guidance contained in Sections 6.2 and 6.3 of Stormwater Design Specification No. 3 (Grass Channels).

6.3. Other Design Issues for Wet Swales

- The average normal pool depth (dry weather) throughout the swale should be 6 inches or less.
- The maximum temporary ponding depth in any single Wet Swale cell should not exceed 18 inches at the most downstream point (e.g., at a check dam or driveway culvert).
- Check dams should be spaced as needed to maintain the effective longitudinal slope identified for the Level 1 or Level 2 design, as appropriate. A typical plan and profile for the check dams is provided in **Figure 11.2** above.
- Individual Wet Swale segments formed by check dams or driveways should generally be at least 25 to 40 feet in length.
- Wet Swale side slopes should be no steeper than 4H:1V to enable wetland plant growth. Flatter slopes are encouraged where adequate space is available, to enhance pre-treatment of sheet flows entering the channel. Under no circumstances are side slopes to steeper than 3H:1V.

6.4. Planting Wet Swales

Designers should choose grass and wetland plant species that can withstand both wet and dry periods as well as relatively high velocity flows within the channel. For a list of wetland plant species suitable for use in Wet Swales, refer to the wetland panting guidance and plant lists provided in Stormwater Design Specification No. 13 (Constructed Wetlands). If roadway salt will be applied to the contributing drainage area, swales should be planted with salt-tolerant non-woody plant species.

6.5. Material Specifications

Consult **Section 6.7** of Stormwater Design Specification No. 3 (Grass Channels) for criteria pertaining to suitable materials for check dams and other swale features.

SECTION 7: REGIONAL & SPECIAL CASE DESIGN ADAPTATIONS

7.1. Karst Terrain

Wet swales are generally *not* feasible in karst terrain, since the water table rarely reaches the land surface**.**

7.2. Coastal Plain

Wet Swales work well in areas of high water table, and consist of a series of on-line or off-line storage cells. Designers should design cells such that the underlying soils are typically saturated, but do not cause standing water between storm events. It may also be advisable to incorporate sand or compost into surface soils to promote a better growing environment. Wet Swales should be planted with wet-footed species, such as sedges or wet meadows. Wet Swales are not recommended in residential areas, due to concerns about mosquito breeding.

7.3 Regenerative Conveyance System (Coastal Plain Outfalls)

Regenerative stormwater conveyance (RSC) systems are open-channel, sand seepage filtering systems that utilize a series of shallow aquatic pools, riffle weir grade controls, native vegetation and underlying sand channel to treat and safely detain and convey storm flow, and convert stormwater to groundwater via infiltration at coastal plain outfalls and other areas where grades make traditional practices difficult to implement. RSC systems combine features and treatment benefits of swales, infiltration, filtering and wetland practices. In addition, they are designed to convey flows associated with extreme floods (i.e., 100 year return frequency event) in a non-erosive manner, which results in a reduction of channel erosion impacts commonly encountered at conventional stormwater outfalls and headwater stream channels.

RCS systems are referred to as Step Pool Storm Conveyance (SPSC) channels in Ann Arundel County, MD where systems have been installed and observed. The physical characteristics of the SPSC channel are best characterized by the Rosgen A or B stream classification types, where "bedform occurs as a step/pool cascading channel which often stores large amounts of sediment in the pools associated with debris dams" (Rosgen, 1996). Due to their ability to safely convey large flood events, RSC systems do not require flow splitters to divert smaller events for water quality treatment, and reduce the need for storm drain infrastructure in the conveyance system.

These structures feature surface/subsurface runoff storage seams and an energy dissipation design that is aimed at attenuating the flow to a desired level through energy and hydraulic power equivalency principles. RSC systems have the added benefit of creating dynamic and diverse ecosystems for a range of plants, animals, amphibians and insects. These ecosystems enhance pollutant uptake and assimilation and provide a natural and native aesthetic at sites. RSC systems are unique in that they can be located on the front or tail end of a treatment system and still provide water quality and groundwater recharge benefits. Where located on the front end of a treatment train, they provide water quality, groundwater recharge, and channel protection, while also providing non-erosive flow conveyance that delivers flow to the stormwater quantity practice - a constructed wetland, wet pond, ED Pond, or combination.

The Ann Arundel County design specification can be found at:
http://www.aacounty.org/DPW/Watershed/StepPoolStormConveyance.cfm

SECTION 8: CONSTRUCTION

Consult the construction criteria outlined in Section 8 of both Stormwater Design Specification No. 3 (Grass Channels) and Stormwater Design Specification No. 13 (Constructed Wetlands). An example construction phase inspection checklist for Wet Swales can be accessed at the CWP website at:

http://www.cwp.org/Resource_Library/Controlling_Runoff_and_Discharges/sm.htm
(scroll to Tool6: Plan Review, BMP Construction, and Maintenance Checklists)

SECTION 9: MAINTENANCE

Wet Swales have maintenance needs similar to Dry Swales, although woody wetland vegetation may need to be removed periodically. Please consult the maintenance criteria outlined in Section 9 of Stormwater Design Specification No. 3 (Grass Channels), Stormwater Design Specification No. 10 (Dry Swales), and Stormwater Design Specification No. 13 (Constructed Wetlands). Example maintenance inspection checklists for Wet Swales can be accessed in Appendix C of Chapter 9 of the *Virginia Stormwater Management Handbook* (2010) or at the CWP website at:

http://www.cwp.org/Resource_Library/Controlling_Runoff_and_Discharges/sm.htm
(scroll to Tool6: Plan Review, BMP Construction, and Maintenance Checklists)

SECTION 10: COMMUNITY & ENVIRONMENTAL CONCERNS

The main concerns of adjacent residents are perceptions that Wet Swales will create nuisance conditions or will be hard to maintain. Common concerns include the continued ability to mow grass, landscaping preferences, and the risks of unsightly weeds, standing water, and mosquitoes breeding. For these reasons, Wet Swales are not recommended in residential settings, because the shallow, standing water in the swale is often viewed as a potential nuisance by homeowners.

SECTION 11: REFERENCES

Anne Arundel County Watershed Ecosystems and Restoration Services, *Step Pool Conveyance Systems*, Annapolis, MD. Available online at: http://www.aacounty.org/DPW/Watershed/StepPoolStormConveyance.cfm

Claytor, R. and T. Schueler. 1996. *Design of Stormwater Filtering Systems*. Center for Watershed Protection. Ellicott City, MD.

Center for Watershed Protection (CWP). 2007. *National Pollutant Removal Performance Database Version 3.0*. Ellicott City, MD.

Maryland Department of Environment (MDE). 2000. *Maryland Stormwater Design Manual*. Baltimore, MD. Available online at: http://www.mde.state.md.us/Programs/WaterPrograms/SedimentandStormwater/stormwater_design/index.asp

Schueler, T., D. Hirschman, M. Novotney and J. Zielinski. 2007. *Urban Stormwater Retrofit Practices*. Manual 3 in the Urban Subwatershed Restoration Manual Series. Center for Watershed Protection, Ellicott City, MD.

Schueler, T. 2008. Technical Support for the Baywide Runoff Reduction Method. Chesapeake Stormwater Network. Baltimore, MD. www.chesapeakestormwater.net

Virginia Stormwater Management Handbook. 1999. *Volumes 1 and 2*. Richmond, VA.

VIRGINIA DEQ STORMWATER
DESIGN SPECIFICATION No. 12

FILTERING PRACTICES

VERSION 1.8
March 1, 2011

SECTION 1: DESCRIPTION

Stormwater filters are a useful practice to treat stormwater runoff from small, highly impervious sites. Stormwater filters capture, temporarily store, and treat stormwater runoff by passing it through an engineered filter media, collecting the filtered water in an underdrain, and then returning it back to the storm drainage system. The filter consists of two chambers: the first is devoted to settling, and the second serves as a filter bed consisting of a sand or organic filter media.

Stormwater filters are a versatile option because they consume very little surface land and have few site restrictions. They provide moderate pollutant removal performance at small sites where space is limited,. However, sand filters have limited or no runoff volume reduction capability, so designers should consider using up-gradient runoff reduction practices, which have the effect of decreasing the Treatment Volume (and size) of the filtering practices. Filtering practices are also suitable to provide special treatment at ~~a~~ designated stormwater hotspots. For a list of potential stormwater hotspots that merit treatment by filtering practices, consult the Stormwater Design Specification No. 8 (Infiltration).

Stormwater filters depend mainly on physical treatment mechanisms to remove pollutants from stormwater runoff, including gravitational settling in the sedimentation chamber, straining at the top of the filter bed, and filtration and adsorption onto the filter media. Microbial films often form on the surface of the filter bed, which can also enhance biological removal. Filters are usually designed only for water quality treatment.

SECTION 2: PERFORMANCE

Table 12.1. Summary of Stormwater Functions Provided by Filtering Practices

Stormwater Function	Level 1 Design	Level 2 Design
Annual Runoff Volume Reduction (RR)	0%	0%
Total Phosphorus (TP) EMC Reduction[1] by BMP Treatment Process	60%	65%
Total Phosphorus (TP) Mass Load Removal	60%	65%
Total Nitrogen (TN) EMC Reduction[1] by BMP Treatment Process	30%	45%
Total Nitrogen (TN) Mass Load Removal	30%	45%
Channel Protection	Limited – The Treatment Volume diverted off-line into a storage facility for treatment can be used to calculate a Curve Number (CN) Adjustment.	
Flood Mitigation	None. Most filtering practices are off-line and do not materially change peak discharges.	
[1] Change in the event mean concentration (EMC) through the practice..		

Sources: CWP and CSN (2008), CWP, 2007

SECTION 3: DESIGN TABLE

The major design goal is to maximize nutrient removal. To this end, designers may choose to go with the baseline design (Level 1) or choose an enhanced Level 2 design that maximizes nutrient removal. To qualify for Level 2, the filter must meet all design criteria shown in the right hand column of Table 2.

Table 12.2. Filtering Practice Design Guidance

Level 1 Design (RR:0; TP:60; TN:30)	Level 2 Design (RR:0 [1]; TP:65; TN:45)
T_V = [(1.0)(Rv)(A)] / 12 – the volume reduced by an upstream BMP	T_V = [(1.25)(Rv)(A)] / 12 – the volume reduced by an upstream BMP
One cell design	Two cell design
Sand media	Sand media with an organic layer
Contributing Drainage Area (CDA) contains pervious area	CDA is nearly 100% impervious
[1] May be increased if the 2nd cell is utilized for infiltration in accordance with Stormwater Design Specification No. 8 (Infiltration) or Stormwater Design Specification No. 9 (Bioretention). The Runoff Reduction (RR) credit should be proportional to the fraction of the T_V designed to be infiltrated.	

SECTION 4: TYPICAL DETAILS

Figures 12.1 and 12.2 provide typical schematics for a surface sand filter and organic filter, respectively.

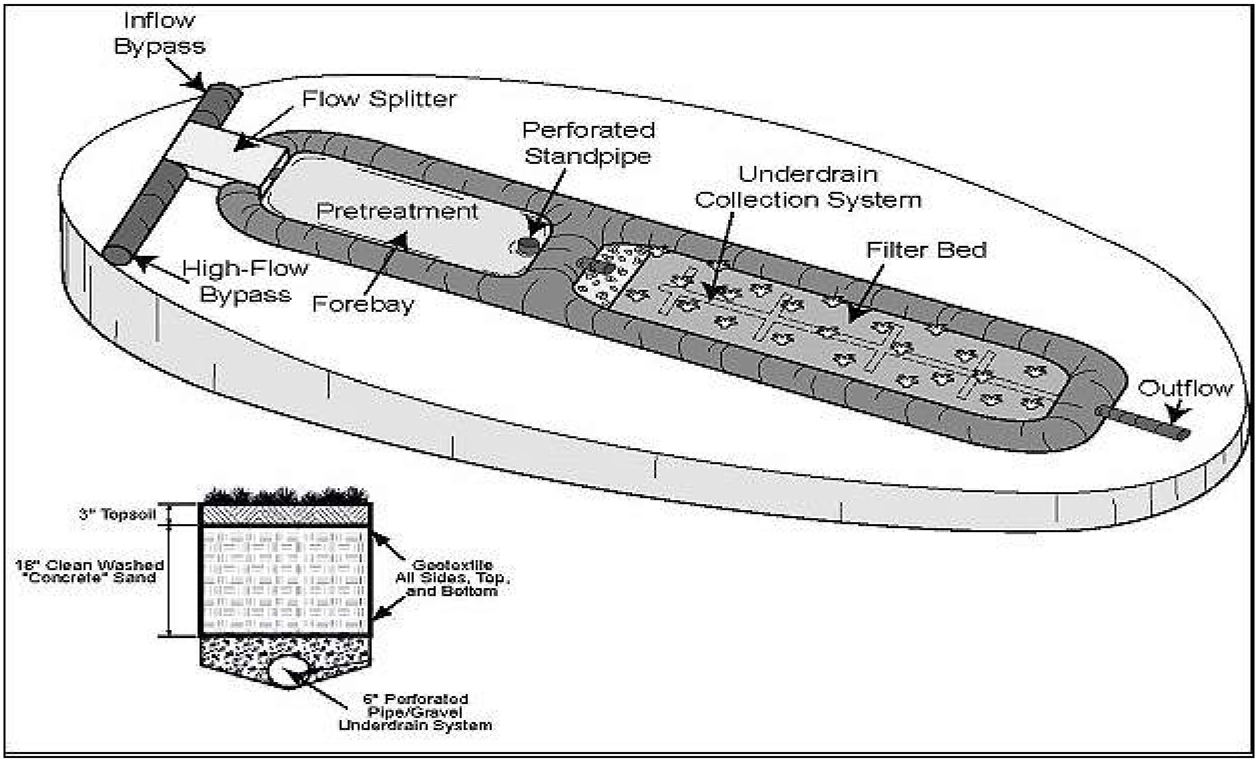


Figure 12.1. Schematic of a Surface Sand Filter

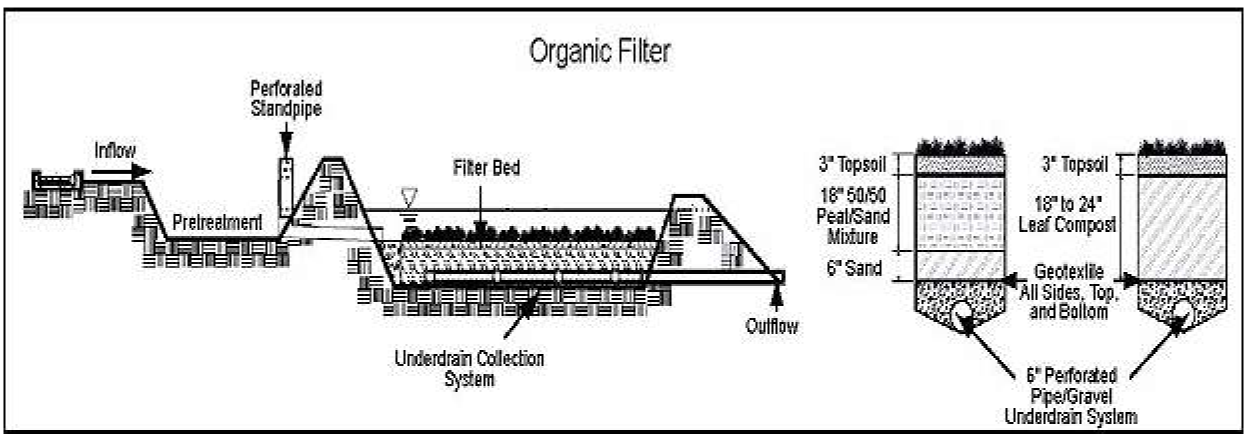


Figure 12.2. Schematic of an Organic Filter

SECTION 5: PHYSICAL FEASIBILITY & DESIGN APPLICATIONS

Stormwater filters can be applied to most types of urban land. They are not always cost-effective, given their high unit cost and small area served, but there are situations where they are clearly the best option (e.g., hotspot runoff treatment, small parking lots, ultra-urban areas etc.). The following is a list of design constraints for filtering practices.

Available Hydraulic Head. The principal design constraint for stormwater filters is available hydraulic head, which is defined as the vertical distance between the top elevation of the filter and the bottom elevation of the existing storm drain system that receives its discharge. The head required for stormwater filters ranges from 2 to 10 feet, depending on the design variant. Thus, it is difficult to employ filters in extremely flat terrain, since they require gravity flow through the filter. The only exception is the Perimeter Sand Filter, which can be applied at sites with as little as 2 feet of head.

Depth to Water Table and Bedrock. The designer must assure a standard separation distance of at least 2 feet between the seasonally high groundwater table and/or bedrock layer and the bottom invert of the filtering practice.

Contributing Drainage Area. Sand filters are best applied on small sites where the contributing drainage (CDA) area is as close to 100% impervious as possible. A maximum CDA of 5 acres is recommended for surface sand filters, and a maximum CDA of 2 acres is recommended for perimeter or underground filters. Filters have been used on larger drainage areas in the past, but greater clogging problems have typically resulted.

Space Required. The amount of space required for a filter practice depends on the design variant selected. Both sand and organic surface filters typically consume about 2% to 3% of the CDA, while perimeter sand filters typically consume less than 1%. Underground stormwater filters generally consume no surface area except their manholes.

As noted above, filters are particularly well suited to treat runoff from stormwater hotspots and smaller parking lots. Other applications include redevelopment of commercial sites or when existing parking lots are renovated or expanded. Filters can work on most commercial, industrial, institutional or municipal sites and can be located underground if surface area is not available.

There are several design variations of the basic sand filter that enable designers to use filters at challenging sites or to improve pollutant removal rates. The most common design variants include the following:

- ***Non-Structural Sand Filter.*** The Non-Structural Sand Filter is applied to sites less than 2 acres in size, and is essentially the same as a Bioretention Basin (see Stormwater Design Specification No. 9), with the following exceptions:
  - The bottom is lined with an impermeable filter fabric and always has an underdrain.
  - The surface cover is sand, turf or pea gravel.
  - The filter media is 100% sand.
  - The filter surface is not planted with trees, shrubs or herbaceous materials.

- The filter has two cells, with a dry or wet sedimentation chamber preceding the sand filter bed.

The Non-Structural Sand Filter is the least expensive filter option for treating hotspot runoff. The use of bioretention areas is generally preferred at most other sites.

Surface Sand Filter. The Surface Sand Filter is designed with both the filter bed and sediment chamber located at ground level. In most cases, the filter chambers are created using pre-cast or cast-in-place concrete. Surface Sand Filters are normally designed to be off-line facilities, so that only the desired water quality or runoff reduction volume is directed to the filter for treatment. However, in some cases they can be installed on the bottom of a Dry Extended Detention (ED) Pond (see **Figure 12.3** and Stormwater Design Specification No. 15).

Figure 12.3. Hybrid Sand filter in a Detention Basin

Organic Media Filter. Organic Media Filters are essentially the same as surface filters, but the sand is replaced with an organic filtering medium. Two notable examples are the peat/sand filter and the compost filter system. Organic filters achieve higher pollutant removal for metals and hydrocarbons due to the increased cation exchange capacity of the organic media.

Underground Sand Filter. The Underground Sand Filter is modified to install the filtering components underground and is often designed with an internal flow splitter or overflow device that bypasses runoff from larger stormwater events around the filter. Underground Sand Filters are expensive to construct, but they consume very little space and are well suited to ultra-urban areas (**Figure 12.4**).

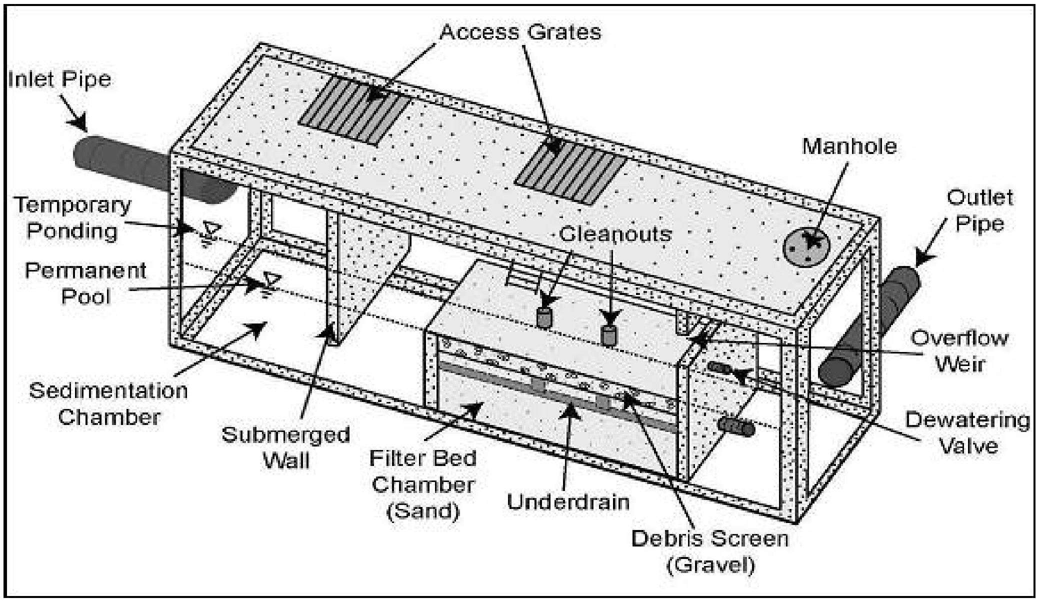


Figure 12.4. Underground Filter Schematic

Perimeter Sand Filter. The Perimeter Sand Filter also includes the basic design elements of a sediment chamber and a filter bed. However, in this design flow enters the system through grates, usually at the edge of a parking lot. The Perimeter Sand Filter is usually designed as an on-line practice (i.e., all flows enter the system), but larger events bypass treatment by entering an overflow chamber. One major advantage of the Perimeter Sand Filter design is that it requires little hydraulic head and is therefore a good option for sites with low topographic relief.

Proprietary Filters. Proprietary filters use various filter media and geometric configurations to achieve filtration within a packaged structure. In some cases, these systems can provide excellent targeting of specific pollutants. However, designers must verify that the particular product has been reviewed and accepted by the Virginia BMP Clearinghouse (http://www.vwrrc.vt.edu/swc/) for use in Virginia.

SECTION 6: DESIGN CRITERIA

6.1. Overall Sizing

Filtering devices are sized to accommodate a specified Treatment Volume. The volume to be treated by the device is a function of the storage depth above the filter and the surface area of the filter. The storage volume is the volume of ponding above the filter. For a given Treatment Volume, **Equation 12.1** is used to determine the required filter surface area:

Equation 12.1. Minimum Filter Surface Area for Filtering Practices

$$A_f = (TV)(d_f)/[(K)(h_f + d_f)(t_f)]$$

Where:

A_f = area of the filter surface (sq. ft.)
TV = Treatment Volume, volume of storage (cu. ft.)
d_f = Filter media depth (thickness) = minimum 1 ft. (ft.)
K = Coefficient of permeability – partially clogged sand (ft./day) = 3.5 ft./day
h_f = Average height of water above the filter bed (ft.), with a maximum of 5 ft./2
t_f = Allowable drawdown time = 1.67 days

The coefficient of permeability (ft./day) is intended to reflect the worst case situation (i.e., the condition of the sand media at the point in its operational life where it is in need of replacement or maintenance). Filtering practices are therefore sized to function within the desired constraints at the end of the media's operational life cycle.

A storage volume of a least 75% of the design Treatment Volume – including the volume over the top of the filter media and the volume in the pretreatment chamber(s), as well as any additional storage – is required in order to capture the volume from high-intensity storms prior to filtration and avoid premature bypass. This reduced volume takes into account the varying filtration rate of the water through the media, as a function of a gradually declining hydraulic head.

Equation 12.2. Required Treatment Volume Storage for Filtering Practices

$$V_s = 0.75(TV)$$

Where:

V_s = Volume of storage (cu. ft.)
TV = Treatment Volume (cu. ft.)

6.2. Soil Testing Requirements

At least one soil boring must be taken at a low point within the footprint of the proposed filtering practice to establish the water table and bedrock elevations and evaluate soil suitability.

6.3. Pre-treatment

Adequate pre-treatment is needed to prevent premature filter clogging and ensure filter longevity. Pre-treatment devices are subject to the following criteria:

- Sedimentation chambers are typically used for pre-treatment to capture coarse sediment particles before they reach the filter bed.
- Sedimentation chambers may be wet or dry but must sized to accommodate at least 25% of the total Treatment Volume (inclusive).

- Non-structural Sand Filters may use alternative pre-treatment measures, such as a compost amended grass filter flow path, forebay, gravel diaphragm, check dam, level spreader, or combination. The filter strip must be a minimum length of 15 feet, have a slope of 3% or less, and contain compost amended soils (see Stormwater Design Specification No. 4). The check dam may be wooden or concrete and must be installed so that it extends only 2 inches above the filter strip and has lateral slots to allow runoff to be evenly distributed across the filter surface. The forebay should be designed to accommodate at least 25% of the total Treatment Volume (inclusive), and contain a non-erosive spillway that distributes the flow evenly over the filter surface.
- If proprietary devices are used for pre-treatment, designers must confirm through the Virginia BMP Clearinghouse that the practice has the capability to effectively trap and retain particles down to 20 microns in size for the design flow rate.
- Sediment chambers should be designed as level spreaders such that inflows to the sand filter bed have near zero velocity and spread runoff evenly across the bed.

6.4. Conveyance and Overflow

Most filtering practices are designed as off-line systems so that all flows enter the filter storage chamber until it reaches capacity, at which point larger flows are then diverted or bypassed around the filter to an outlet chamber and are not treated. Runoff from larger storm events should be bypassed using an overflow structure or a flow splitter. Claytor and Schueler (1996) and ARC (2001) provide design guidance for flow splitters for filtering practices.

Some underground filters will be designed and constructed as on-line BMPs. In these cases, designers must indicate how the device will safely pass the local design storm (e.g., 10 year event) without resuspending or flushing previously trapped material.

All stormwater filters should be designed to drain or dewater within 40 hours after a storm event to reduce the potential for nuisance conditions.

Stormwater filters are normally designed with an impermeable liner and underdrain system that meet the criteria provided in **Table 4 12.3** below.

6.5. Filter Media and Surface Cover

Type of Media. The normal filter media consists of clean, washed concrete sand with individual grains between 0.02 and 0.04 inches in diameter. Alternatively, organic media can be used, such as a peat/sand mixture or a leaf compost mixture. The decision to use organic media in a stormwater filter depends on which stormwater pollutants are targeted for removal. Organic media may enhance pollutant removal performance with respect to metals and hydrocarbons (Claytor and Schueler, 1996). ***However, recent research has shown that organic media can actually leach soluble nitrate and phosphorus back into the discharge water, making it a poor choice when nutrients are the pollutant of concern***.

Type of Filter. The choice of which sand filter design to apply depends on available space and hydraulic head and the level of pollutant removal desired. In ultra-urban situations where surface space is at a premium, underground sand filters are often the only design that can be used. Surface and perimeter filters are often a more economical choice when adequate surface area is available.

Surface Cover. The surface cover for structural and non-structural Surface Sand Filters should consist of a 3-inch layer of topsoil on top of a non-woven filter fabric laid above the sand layer. The surface may also have pea gravel inlets in the topsoil layer to promote filtration. The pea gravel may be located where sheet flow enters the filter, around the margins of the filter bed, or at locations in the middle of the filter bed.

Underground sand filters should have a pea gravel layer on top of a coarse non-woven fabric laid over the sand layer. The pea-gravel helps to prevent bio-fouling or blinding of the sand surface. The fabric serves to facilitate removing the gravel during maintenance operations.

Depth of Media. The depth of the filter media plays a role in how quickly stormwater moves through the filter bed and how well it removes pollutants. Recent design guidance recommends a minimum filter bed depth ranging from 12 to 18 inches. Greater depths can be used in order to facilitate the removal of 1 to 3 inches of sand during maintenance withough having to necessarily replace it.

Impervious Drainage Area. The contributing drainage area should be as close to 100% impervious as possible in order to reduce the risk that eroded sediments will clog the filter.

6.6. Maintenance Reduction Features

The following maintenance issues should be addressed during filter design to reduce future maintenance problems:

- ***Observation Wells and Cleanouts.*** Surface Sand Filters should include an observation well consisting of a 6-inch diameter non-perforated PVC pipe fitted with a lockable cap. It should be installed flush with the ground surface to facilitate periodic inspection and maintenance. In most cases, a cleanout pipe will be tied into the end of all underdrain pipe runs. The portion of the cleanout pipe/observation well in the underdrain layer should be perforated. At least one cleanout pipe must be provided for every 2000 square feet of filter surface area.
- ***Access.*** Good maintenance access is needed to allow crews to perform regular inspections and maintenance activities. "Sufficient access" is operationally defined as the ability to get a vacuum truck or similar equipment close enough to the sedimentation chamber and filter to enable cleanouts.
- ***Manhole Access (for Underground Filters).*** Access to the headbox and clearwell of Underground Filters must be provided by manholes at least 30 inches in diameter, along with steps to the areas where maintenance will occur.
- ***Visibility.*** Stormwater filters should be clearly visible at the site so inspectors and maintenance crews can easily find them. Adequate signs or markings should be provided at manhole access points for Underground Filters.
- ***Confined Space Issues.*** Underground Filters are often classified as an *underground confined space*. Consequently, special OSHA rules and training are needed to protect the workers that

access them. These procedures often involve training about confined space entry, venting, and the use of gas probes.

6.7. Filtering Material Specifications

The basic material specifications for filtering practices are outlined in **Table 12.3**.

Table 12.3. Filtering Practice Material Specifications

Material	Specification
Sand	Clean AASHTO M-6/ASTM C-33 medium aggregate concrete sand with a particle size range of 0.02 to 0.04 inch in diameter.
Organic Layer	The compost shall generally conform to the requirements contained in Stormwater Design Specification No. 4 (Soil Compost Amendments). Leaf compost should be made exclusively of fallen deciduous leaves with less than 5% dry weight of woody or green yard debris materials. The compost shall contain less than 0.5% foreign material, such as glass or plastic contaminants, and shall be certified as pesticide free. The use of leaf mulch, composted mixed yard debris, biosolids, mushroom compost or composted animal manures is prohibited. The compost shall be matured (i.e., composted for a period of at least 1year) and exhibit no further decomposition. Visual appearance of leaf matter in the compost is not acceptable. The compost should have a dry bulk density ranging from 40 to 50 lbs/cu. ft., a pH of 6 to 8, and a Cation Exchange Capacity (CEC) equal to or greater than 50 meq/100 grams of dry weight.
Underdrain	High Density Polyethylene (HDPE) smooth or corrugated flexible-wall pipe is acceptable to some local governments. Pipes must comply with ASHTO M252 and ASTM F405. Underdrains meeting ASTM F758 should be perforated with slots that have a maximum width of 3/8 inch and provide a minimum inlet area of 1.76 square inches per linear foot of pipe. Underdrains meeting ASTM F949 should be perforated with slots with a maximum width of 1/8 inch that provide a minimum inlet area of 1.5 square inches per linear foot of pipe. Underdrain pipe supplied with precision-machined slots provides greater intake capacity and superior clog-resistant drainage of fluids, as compared to standard round-hole perforated pipe. Slotted underdrain reduces entrance velocity into the pipe, thereby reducing the possibility that solids will be carried into the system. Slot rows can generally be positioned symmetrically or asymmetrically around the pipe circumference, depending upon the application.
Filter Fabric	Use needled, non-woven, polypropylene geotextile meeting the following specifications: Grab Tensile Strength (ASTM D4632) = $\geq$ 120 lbs Mullen Burst Strength (ASTM D3786) = $\geq$ 225 lbs/sq. in. Flow Rate (ASTM D4491) = $\geq$ 125 gpm/sq. ft. Apparent Opening Size (ASTM D4751) = US #70 or #80 sieve NOTE: Heat-set or heat-calendared fabrics are not recommended.
Stone Jacket for Underdrain	Use gravel that meets VDOT #57 stone specifications or the ASTM equivalent (1 inch maximum).

SECTION 7: REGIONAL & SPECIAL CASE DESIGN ADAPTATIONS

7.1. Karst Terrain

Stormwater filters are a good option in karst areas, since they are not connected to groundwater and therefore minimize the risk of sinkhole formation and groundwater contamination. Construction inspection should certify that the filters are indeed water tight and that excavation will not extend into a karst layer.

7.2. Coastal Plain

The flat terrain, low head and high water table of the coastal plain make several filter designs difficult to implement. However, the Perimeter Sand Filter and the Non-Structural Sand Filter generally have low head requirements and can work effectively at many small coastal plain sites, subject to the following criteria:

- The combined depth of the underdrain and sand filter bed can be reduced to from 24 to 30 inches.
- The designer may wish to maximize the length of the stormwater filter or provide treatment in multiple connected cells.
- The minimum depth to the seasonally high groundwater table may be relaxed to 1 foot, as long as the filter is equipped with a large diameter underdrain (e.g., 6 inches) that is only partially efficient at dewatering the filter bed.
- It is important to maintain at least a 0.5% slope of the underdrain to ensure drainage and to tie it into the receiving ditch or conveyance system.

7.3. Steep Terrain

The gradient of slopes contributing runoff to sand filters can be increased to 15% in areas of steep terrain, as long as a two cell, terraced design is used to dissipate erosive energy prior to filtering. The drop in elevation between cells should be limited to 1 foot and the slope should be armored with river stone or a suitable equivalent.

7.4. Cold Climate and Winter Performance

Surface or perimeter filters may not always be effective during the winter months. The main problem is ice that forms over and within the filter bed. Ice formation may briefly cause nuisance flooding if the filter bed is still frozen when spring melt occurs. To avoid these problems, filters should be inspected before the onset of winter (prior to the first freeze) to dewater wet chambers and scarify the filter surface. Other measures to improve winter performance include the following:

- Place a weir between the pre-treatment chamber and filter bed to reduce ice formation; the weir is a more effective substitute than a traditional standpipe orifice.
- Extend the filter bed below the frost line to prevent freezing within the filter bed.

- Oversize the underdrain to encourage more rapid drainage and to minimize freezing of the filter bed.
- Expand the sediment chamber to account for road sand. Pre-treatment chambers should be sized to accommodate up to 40% of the Treatment Volume.

7.5. Linear Highway Sites

Non-Structural Sand Filters are a preferred practice for constrained highway rights-of-way when designed as a series of individual on-line or off-line cells. In these situations, the final design closely resembles that of Dry Swales. Salt-tolerant grass species should be selected if the contributing roadway will be salted in the winter.

SECTION 8: CONSTRUCTION

8.1. Construction Sequence

The following is the typical construction sequence to properly install a structural Sand Filter. This sequence can be modified to reflect different filter designs, site conditions, and the size, complexity and configuration of the proposed filtering application.

Step 1: Use of Filtering Practices as an E&S Control. The future location of a filtering practice may be used as the site of a temporary sediment basin or trap during site construction, as long as design elevations are set with final cleanout and conversion in mind. The bottom elevation of the filtering practice should be lower than the bottom elevation of the temporary sediment basin. Appropriate procedures should be implemented to prevent discharge of turbid waters when the temporary basin is converted to a filtering practice.

Step 2: Stabilize Drainage Area. Filtering practices should only be constructed after the contributing drainage area to the facility is completely stabilized, so sediment from the CDA does not flow into and clog the filter. If the proposed filtering area is used as a sediment trap or basin during the construction phase, the construction notes should clearly specify that, after site construction is comlete, the sediment control facility will be dewatered, dredged and regraded to design dimensions for the post-construction filter.

Step 3: Install E&S Controls for the Filtering Practice. Stormwater should be diverted around filtering practices as they are being constructed. This is usually not difficult to accomplish for off-line filtering practices. It is extremely important to keep runoff and eroded sediments away from the Sand Filter throughout the construction process. Silt fence or other sediment controls should be installed around the perimeter of the Sand Filter, and erosion control fabric may be needed during construction on exposed side-slopes with gradients exceeding 4H:1V. Exposed soils in the vicinity of the filtering practice should be rapidly stabilized by hydro-seed, sod, mulch or other locally approved method of soil stabilization.

Step 4: Assemble Construction Materials on-site, make sure they meet design specifications, and prepare any staging areas.

Step 5: Clear and Strip the project area to the desired subgrade.

Step 6: Excavate/Grade until the appropriate elevation and desired contours are achieved for the bottom and side slopes of the filtering practice.

Step 7: Install the Filter Structure and check all design elevations (concrete vaults for surface, underground and perimeter sand filters). Upon completion of the filter structure shell, inlets and outlets should be temporarily plugged and the structure filled with water to the brim to demonstrate watertightness. Maximum allowable leakage is 5% of the water volume in a 24-hour period. If the structure fails the test, repairs must be performed to make the structure watertight before any sand is placed into it.

Step 8: Install the gravel, underdrains, and choker layer of the filter.

Step 9. Spread Sand Across the Filter Bed in 1 foot lifts up to the design elevation. Backhoes or other equipment can deliver the sand from outside the sand filter structure. Sand should be manually raked. Clean water is then added until the sedimentation chamber and filter bed are completely full. The facility is then allowed to drain, hydraulically compacting the sand layers. After 48 hours of drying, refill the structure to the final top elevation of the Sand Filter bed.

Step 10: Install the Permeable Filter Fabric over the sand, add a 3-inch topsoil layer and pea gravel inlets, and immediately seed with the permanent grass species. The grass should be watered, and the facility should not be switched on-line until a vigorous grass cover has become established.

Step 11:. Stabilize Exposed Soils on the perimeter of the structure with temporary seed mixtures appropriate for a buffer. All areas above the normal pool should be permanently stabilized by hydroseeding or seeding over straw.

Step 12. Conduct the final construction inspection (see **Section 8.2**).

8.2. Construction Inspection

Multiple construction inspections are critical to ensure that stormwater filters are properly constructed. Inspections are recommended during the following stages of construction:

- Pre-construction meeting.
- Initial site preparation (including installation of project E&S controls).
- Excavation/grading to design dimensions and elevations.
- Installation of the filter structure, including the watertightness test.
- Installation of the underdrain and sand filter bed.
- Check off that turf cover is vigorous enough to switch the facility on-line.
- Final Inspection (after a rainfall event to ensure that it drains properly and all pipe connections are watertight. Develop a punch list for facility acceptance. Log the filtering practice's GPS coordinates and submit them for entry into the local BMP maintenance tracking database.

A construction inspection form for Filtering Practices can be accessed at the CWP website at:

http://www.cwp.org/Resource_Library/Controlling_Runoff_and_Discharges/sm.htm
(scroll to Tool6: Plan Review, BMP Construction, and Maintenance Checklists)

SECTION 9: MAINTENANCE

9.1. Maintenance Agreements

Section 4 VAC 50-60-124 of the regulations specifies the circumstances under which a maintenance agreement must be executed between the owner and the local program. This section sets forth inspection requirements, compliance procedures if maintenance is neglected, notification of the local program upon transfer of ownership, and right-of-entry for local program personnel.

9.2. Maintenance Inspections

Regular inspections are critical to schedule sediment removal operations, replace filter media, and relieve any surface clogging. Frequent inspections are especially needed for underground and perimeter filters, since they are out of sight and can be easily forgotten. Depending on the level of traffic or the particular land use, a filter system may either become clogged within a few months of normal rainfall, or could possibly last several years with only routine maintenance. Maintenance inspections should be conducted within 24 hours following a storm that exceeds 1/2 inch of rainfall, to evaluate the condition and performance of the filtering practice, including checking for the following:

- Check to see if sediment accumulation in the sedimentation chamber has exceeded 6 inches. If so, schedule a cleanout.
- Check to see if inlets and flow splitters are clear of debris and are operating properly.
- Check the dry sediment chamber and sand filter bed for any evidence of standing water or ponding more than 48 hours after a storm, and take neceesary corrective action to restore permeability.
- Inspect whether the contributing drainage area to the filter is stable and not a source of sediment.
- Dig a small test pit in the sand filter bed to determine whether the first 3 inches of sand are visibly discolored and need replacement.
- Check whether turf on the filter bed and buffer is more than 12 inches high, and schedule necessary mowing operations.
- Check the integrity of observation wells and cleanout pipes.
- Check concrete structures and outlets for any evidence of spalling, joint failure, leakage, corrosion, etc.
- Ensure that the filter bed is level and remove trash and debris from the filter bed. Sand or gravel covers should be raked to a depth of 3 inches. Filters with a turf cover should have 95% vegetative cover.

The results of the inspection will then determine the level of maintenance required (routine or major – see **Table 12.4**) Example maintenance inspection checklists for Filtering Practices can be accessed in Appendix C of Chapter 9 of the *Virginia Stormwater Management Handbook* (2010) or at CWP website at:

http://www.cwp.org/Resource_Library/Controlling_Runoff_and_Discharges/sm.htm
(scroll to Tool6: Plan Review, BMP Construction, and Maintenance Checklists)

9.3. Routine Maintenance Tasks

A cleanup should be scheduled at least once a year to remove trash and floatables that accumulate in the pretreatment cells and filter bed. Frequent sediment cleanouts in the dry and wet sedimentation chambers are recommended every 2 to 3 years to maintain the function and performance of the filter. If the filter treats runoff from a stormwater hotspot, crews may need to test the filter bed media before disposing of the media and trapped pollutants. Testing is not needed if the filter does not receive runoff from a designated stormwater hotspot, in which case the media can be safely disposed by either land application or land filling.

Table 12.4. Suggested Annual Maintenance Activities for Filtering Practices

Maintenance Tasks	Frequency
• Mow grass filter strips and perimeter turf.	At least four times a year
• Remove blockages and obstructions from inflows • Relieve clogging • Stabilize contributing drainage area and side-slopes to prevent erosion	As needed
• Inspection and cleanup	Annually
• Cleanout wet sedimentation chambers • Remove sediments from dry sedimentation chamber	Once every 2 to 3 years
• Replace top sand layer • Till or aerate surface to improve infiltration/grass cover	Every 5 years

SECTION 10: COMMUNITY & ENVIRONMENTAL CONCERNS

Stormwater filters have a few community and environmental concerns. Their main drawback is their appearance – many filtering practices are imposing concrete boxes that tend to accumulate a lot of trash and debris. Designers should focus on aesthetics to make sure filtering practices are integrated aesthetically into the landscape. Also, there is a small risk that underground and perimeter filters may create a potential habitat for mosquitoes to breed. If this is a community concern, designers should shift to dry sedimentation chambers rather than wet chambers.

SECTION 11: REFERENCES

Atlanta Regional Commission (ARC). 2001. *Georgia Stormwater Management Manual, First Edition*. Available online at: http://www.georgiastormwater.com

Claytor, R. and T. Schueler. 1996. *Design of Stormwater Filtering Systems*. Chesapeake Research Consortium and the Center for Watershed Protection. Ellicott City, MD. http://www.cwp.org/PublicationStore/special.htm

CWP. 2007. *National Pollutant Removal Performance Database Version 3.0*. Center for Watershed Protection, Ellicott City, MD.

District of Columbia Stormwater Management Guidebook. Available online at: http://dchealth.dc.gov/DOH/site/default.asp?dohNav=|33110|

Maryland Department of Environment. *Maryland Stormwater Design Manual.* Available online: http://www.mde.state.md.us/Programs/WaterPrograms/SedimentandStormwater/stormwater_design/index.asp

Minnesota Stormwater Steering Committee (MSSC). 2005. *The Minnesota Stormwater Manual*. http://www.pca.state.mn.us/water/stormwater/stormwater-manual.html

Northern Virginia Regional Commission. 2007. *Low Impact Development Supplement to the Northern Virginia BMP Handbook*. Fairfax, Virginia.

Schueler et al. 2007. *Urban Stormwater Retrofit Practices*. Manual 3 in the Urban Subwatershed Restoration Manual Series. Center for Watershed Protection. Ellicott City, MD.

Schueler, T. 2008. Technical Support for the Baywide Runoff Reduction Method. Chesapeake Stormwater Network. Baltimore, MD. www.chesapeakestormwater.net

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 13

CONSTRUCTED WETLANDS

VERSION 1.9
March 1, 2011

SECTION 1: DESCRIPTION

Constructed wetlands, sometimes called stormwater wetlands, are shallow depressions that receive stormwater inputs for water quality treatment. Wetlands are typically less than 1 foot deep (although they have greater depths at the forebay and in micropools) and possess variable microtopography to promote dense and diverse wetland cover (**Figure 13.1**). Runoff from each new storm displaces runoff from previous storms, and the long residence time allows multiple pollutant removal processes to operate. The wetland environment provides an ideal environment for gravitational settling, biological uptake, and microbial activity. Constructed wetlands are the final element in the roof-to-stream runoff reduction sequence. They should only be considered for use after all other upland runoff reduction opportunities have been exhausted and there is still a remaining water quality or Channel Protection Volume to manage.

SECTION 2: PERFORMANCE

The overall stormwater functions of constructed wetlands are summarized in **Table 13.1**.

Table 13.1. Summary of Stormwater Functions Provided by Constructed Wetlands

Stormwater Function	Level 1 Design	Level 2 Design
Annual Runoff Volume Reduction (RR)	0%	0%
Total Phosphorus (TP) EMC Reduction[1] by BMP Treatment Process	50%	75%
Total Phosphorus (TP) Mass Load Removal	50%	75%
Total Nitrogen (TN) EMC Reduction[1] by BMP Treatment Process	25%	55%
Total Nitrogen (TN) Mass Load Removal	25%	55%
Channel Protection	Yes. Up to 1 foot of detention storage volume can be provided above the normal pool.	
Flood Mitigation	Yes. Flood control storage can be provided above the normal pool.	
[1] Change in event mean concentration (EMC) through the practice.		

Sources: CWP and CSN (2008), CWP, 2007

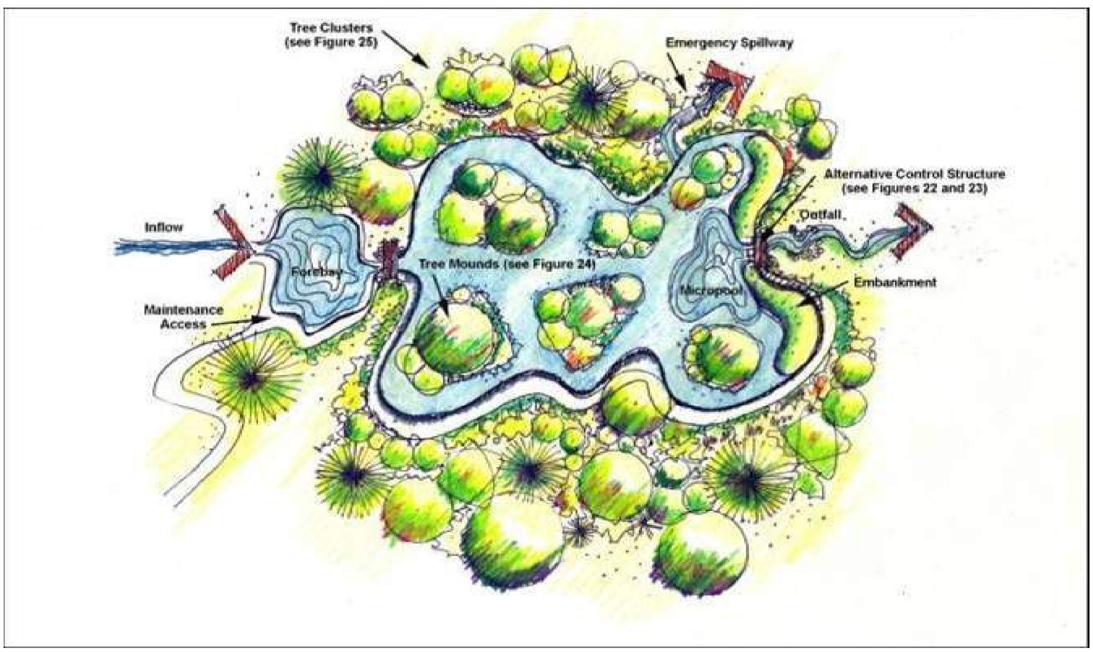


Figure 13.1: Plan View Constructed Wetland Basin

SECTION 3: DESIGN TABLE

The two levels of design that enable constructed wetlands to maximize nutrient reduction are shown in **Table 13.2** below. At this point, there is no runoff volume reduction credit for constructed wetlands, although this may change based on future research.

Table 13.2. Constructed Wetland Design Criteria

Level 1 Design (RR:0; TP:50; TN:25)	Level 2 Design (RR:0; TP:75; TN:55)
$T_V = [(R_V)(A)] / 12$ – the volume reduced by an upstream BMP	$Tv = [1.5(R_V)(A)] / 12$ – the volume reduced by an upstream BMP
Single cell (with a forebay)[1,2]	Multiple cells or a multi-cell pond/wetland combination[1,2]
Extended Detention (ED) for T_V (24 hr)[3] or Detention storage (up to 12 inches) above the wetland pool for channel protection (1-year storm event)	No ED. (limited water surface fluctuations allowed during the 1-inch and 1-year storm events – refer to **Section 6)**
Uniform wetland depth [2]	Diverse microtopography with varying depths [2]
Mean wetland depth is *more* than 1 foot	Mean wetland depth is *less* than 1 foot
The surface area of the wetland is *less* than 3% of the contributing drainage area (CDA).	The surface area of the wetland is *more* than 3% of the CDA.
Length/Width ratio *OR* Flow path = 2:1 or more	Length/Width ratio *OR* Flow path = 3:1 or more
Length of shortest flow path/overall length = 0.5 or more [3]	Length of shortest flow path/overall length = 0.8 or more [4]
Emergent wetland design	Mixed wetland design
[1] Pre-treatment Forebay required – refer to **Section 6.4** [2] Internal Tv storage volume geometry – refer to **Section 6.6** [3] Extended Detention may be provided to meet a maximum of 50% of the Treatment Volume; Refer to Design Specification 15 for ED design [4] In the case of multiple inlets, the flow path is measured from the dominant inlets (that comprise 80% or more of the total pond inflow)	

SECTION 4: TYPICAL DETAILS

Typical details for the three major constructed wetland variations are provided in **Figures 13.2 to 13.4**.

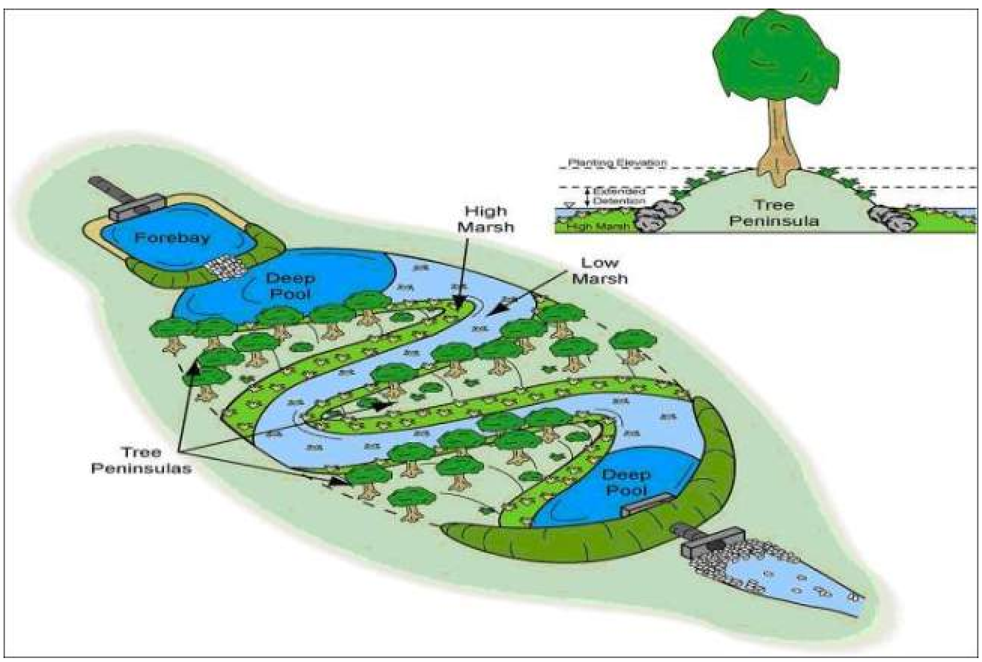
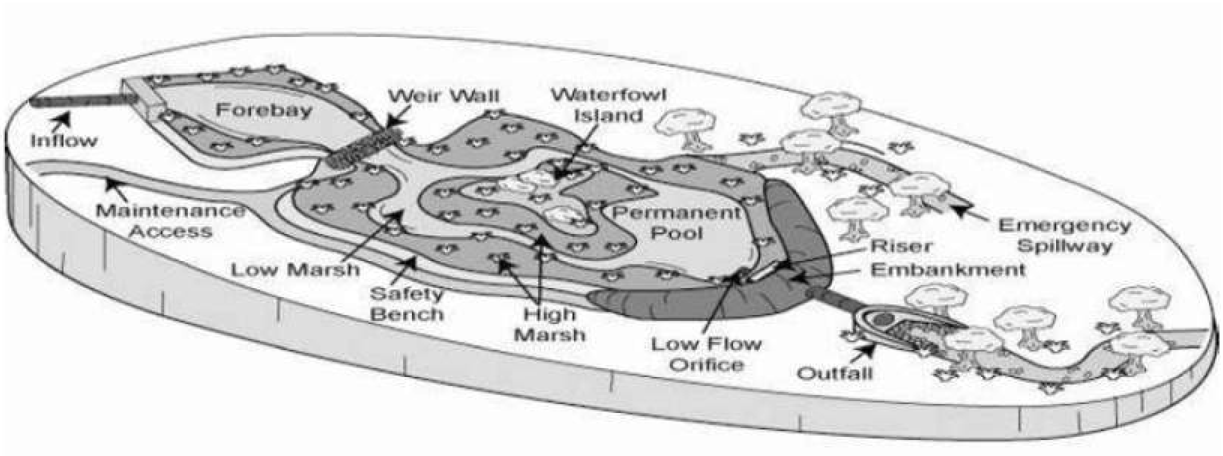
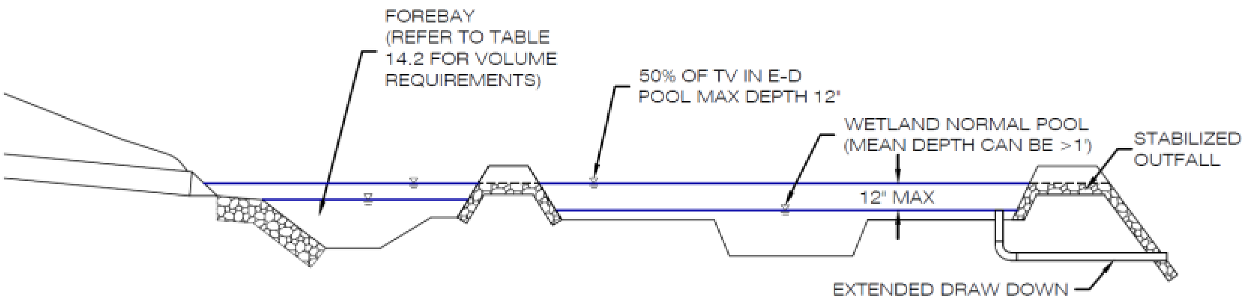


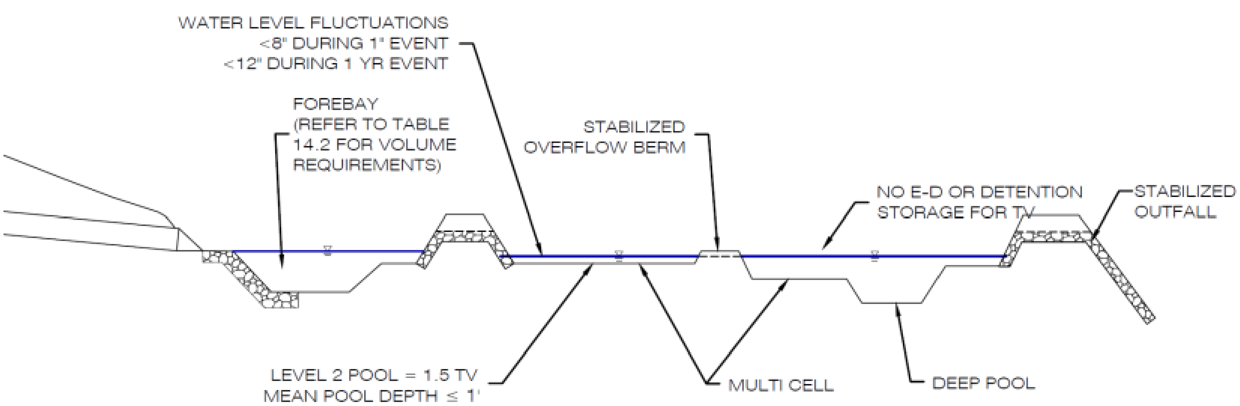
Figure 13.2. Mixed Wetland (Emergent and Forested) Basin



Plan View

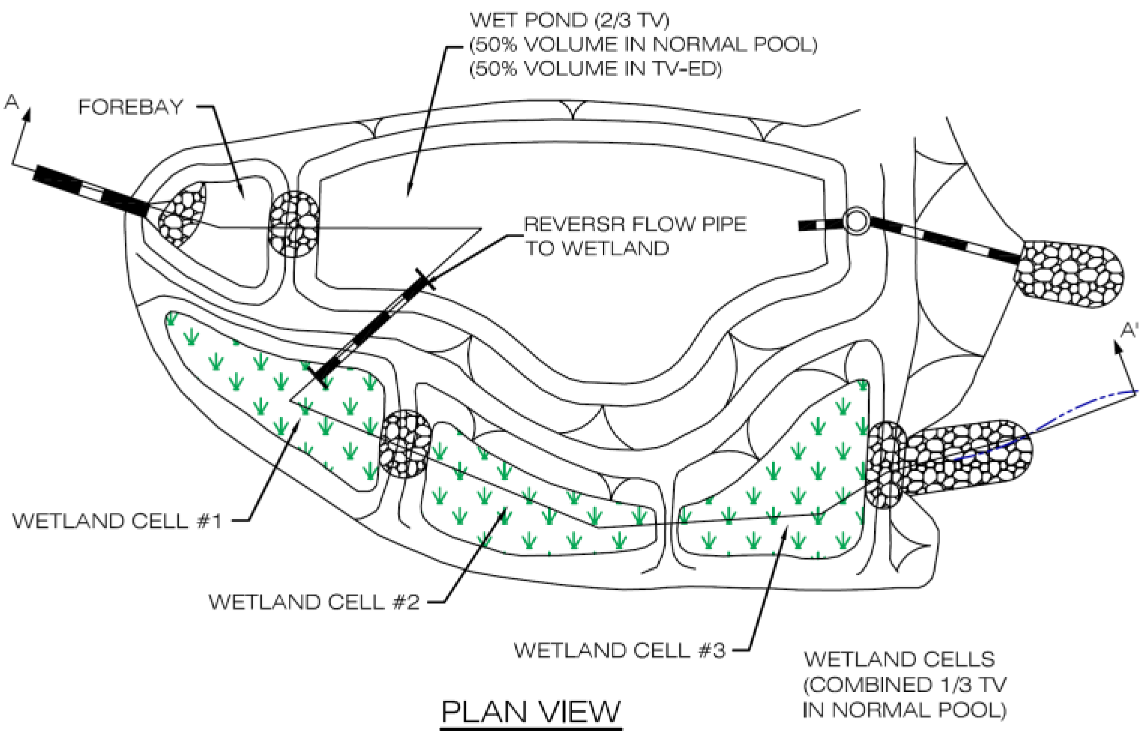


Typical Cross-Section Level 1



Typical Cross Section Level 2

Figure 13.3. Plan and Cross-Sections of Constructed Wetland Level I and Level 2 Configurations



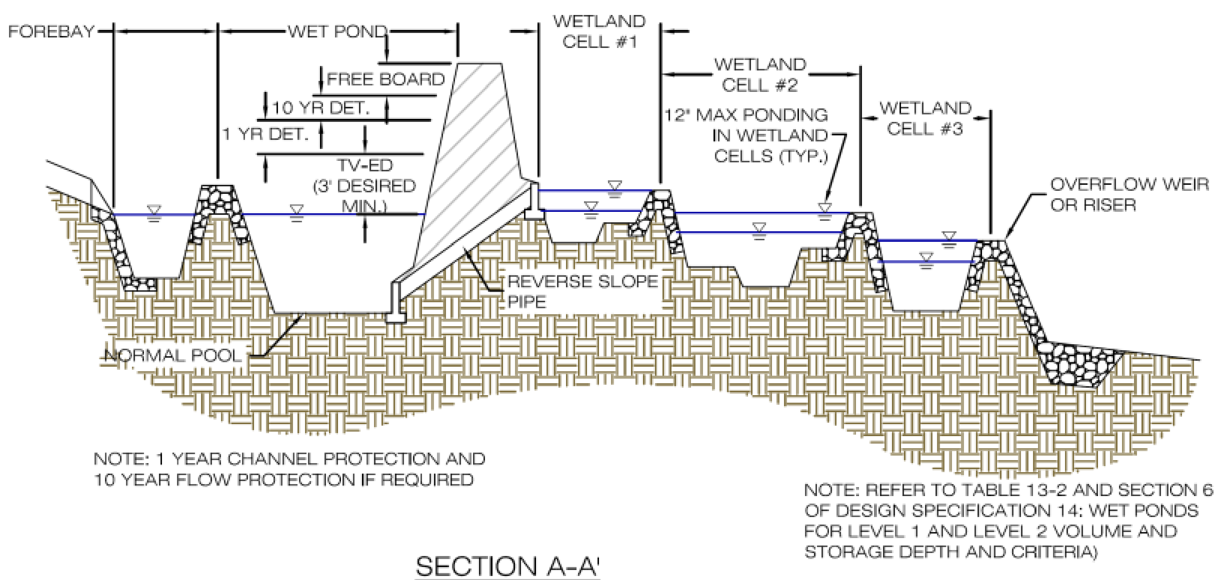


Figure 13.4. Pond-Wetland Combination – Plan and Section

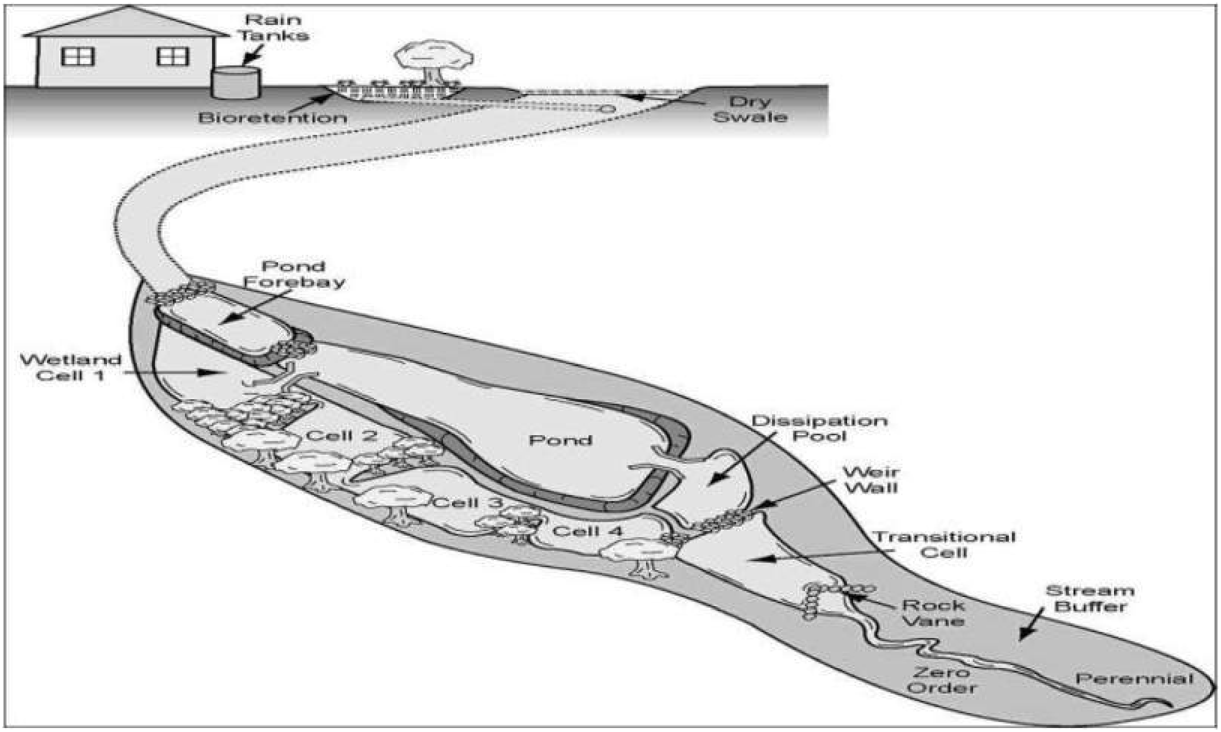


Figure 13.5. Pond-Wetland Combination

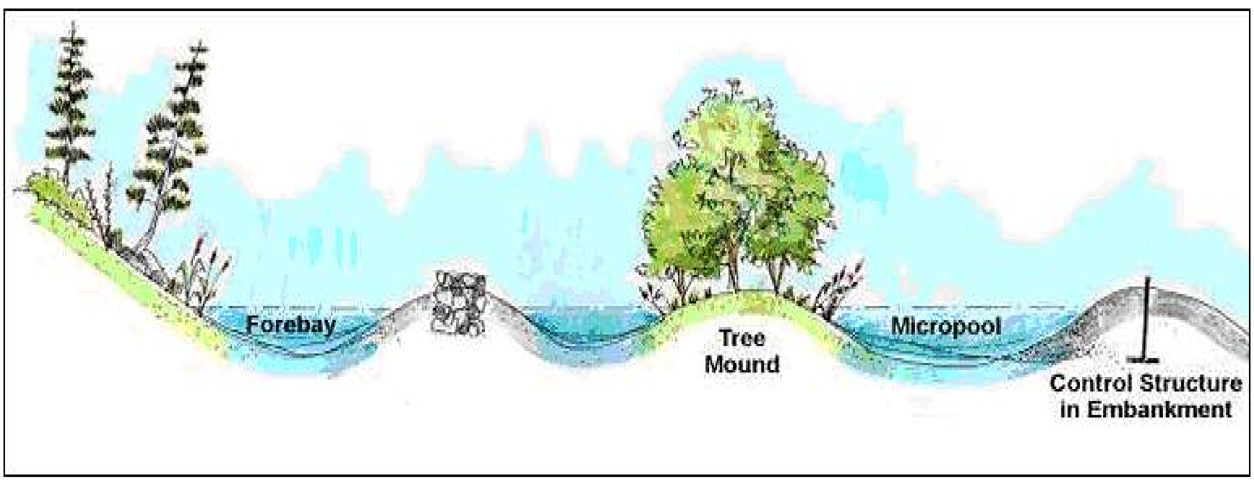


Figure 13.6. Cross Section of Linear Wetland Cell

SECTION 5: PHYSICAL FEASIBILITY & DESIGN APPLICATIONS

Constructed wetland designs are subject to the following site constraints.

Adequate Water Balance. The proposed wetland must have enough water supplied from groundwater, runoff or baseflow so that the wetland micropools will not go completely dry after a 30-day summer drought. A simple water balance calculation must be performed using the equation provided in **Section 6.2**.

Contributing Drainage Area (CDA). The contributing drainage area must be large enough to sustain a permanent water level within the stormwater wetland. If the only source of wetland hydrology is stormwater runoff, then several dozen acres of drainage area are typically needed to maintain constant water elevations. Smaller drainage areas are acceptable if the bottom of the wetland intercepts the groundwater table or if the designer or approving agency is willing to accept periodic wetland drawdown.

Space Requirements. Constructed wetlands normally require a footprint that takes up about 3% of the contributing drainage area, depending on the average depth of the wetland and the extent of its deep pool features.

Available Hydraulic Head. The depth of a constructed wetland is usually constrained by the hydraulic head available on the site. The bottom elevation is fixed by the elevation of the existing downstream conveyance system to which the wetland will ultimately discharge. Because constructed wetlands are typically shallow, the amount of head needed (usually a minimum of 2 to 4 feet) is typically less than for wet ponds.

Steep Slopes. A modification of the Constructed Wetland (and linear wetland or wet swale system) is the Regenerative Conveyance System (RCS). The RCS can be used to bring stormwater down steeper grades through a series of step pools. This can serve to bring stormwater down the coastal plain outfalls where steep drops on the edge of the tidal receiving system can create design challenges. Refer to Section 7: Regional and Special Case Design Adaptations.

Minimum Setbacks. Local ordinances and design criteria should be consulted to determine minimum setbacks to property lines, structures, utilities, and wells. As a general rule, the edges of constructed wetlands should be located at least 10 feet away from property lines, 25 feet from building foundations, 50 feet from septic system fields, and 100 feet from private wells.

Depth to Water Table. The depth to the groundwater table is not a major constraint for constructed wetlands, since a high water table can help maintain wetland conditions. However, designers should keep in mind that high groundwater inputs may reduce pollutant removal rates and increase excavation costs (refer to Section 7.2 of Stormwater Design Specification No. 14: Wet Pond).

Soils. Geotechnical tests should be conducted to determine the infiltration rates and other subsurface properties of the soils underlying the proposed wetland. If soils are permeable or karst geology is a concern (see **Section 7.1**), it may be necessary to use an impermeable liner.

Trout Streams. The use of constructed wetlands in watersheds containing trout streams is generally ***not*** recommended due to the potential for stream warming, ***unless*** (1) all other upland runoff reduction opportunities have been exhausted, (2) the Channel Protection Volume has not been provided, and (3) a linear/mixed wetland design is applied to minimize stream warming.

Use of or Discharges to Natural Wetlands. It can be tempting to construct a stormwater wetland *within* an existing natural wetland, but ***this should never be done unless*** it is part of a broader effort to restore a degraded urban wetland and is approved by the local, state, and/or federal wetland regulatory authority. Constructed wetlands may not be located within jurisdictional waters, including wetlands, without obtaining a section 404 permit from the appropriate local, state, and/or federal regulatory agency. In addition, designer should investigate the status of adjacent wetlands to determine if the discharge from the constructed wetland will change the hydroperiod of a downstream natural wetland (see Wright et al, 2006 for guidance on minimizing stormwater discharges to existing wetlands).

Regulatory Status. Constructed wetlands built for the express purpose of stormwater treatment are not considered jurisdictional wetlands in most regions of the country, but designers should check with their wetland regulatory authorities to ensure this is the case.

Perennial streams. Locating a constructed wetland along or within a perennial stream is strongly discouraged and will require both ~~a~~ Section 401 and Section 404 permits from the state or federal regulatory authority.

Design Applications

Constructed wetlands are designed based on three major factors: (1) **the desired plant community** (an emergent wetland – Level 1 design; a mixed wetland – emergent and forest; or an emergent/pond combination – Level 2 design); (2) **the contributing hydrology** (groundwater, surface runoff or dry weather flow); and (3) the **landscape position** (linear or basin).

To simplify design, three basic design variations are presented for constructed wetlands:

1. Constructed wetland basin – Level 1 design
2. Constructed multi-cell wetland – Level 2 design
3. Constructed multi-cell pond/wetland combination – Level 2 design (see **Figure 13.5**)

> ***IMPORTANT NOTE: Two wetland designs that have been referenced in past design manuals (Schueler, 1992) are no longer allowed or are highly constrained. These include the extended detention (ED) wetland (with more than 1 foot of vertical extended detention storage) and the pocket wetland (unless it has a reliable augmented water source, such as the discharge from a rain tank).***

A *Constructed Wetland Basin* (Level 1 design) consists of a single cell (including a forebay) with a uniform water depth. A portion of the Treatment Volume can be in the form of extended detention (ED) above the wetland pool (refer to Design Specification 15: ED Ponds for the ED design criteria). In addition, channel protection detention (1-year) ponding is allowed above the wetland pool. However, the storage depth for the T_v and channel protection above the pool is limited to 12 inches (the T_v extended detention and 1-year storm detention is inclusive – not additive). Constructed wetland basins can be used at the terminus of a storm drain pipe or open channel (usually after upland opportunities for runoff reduction have also been applied). They generally follow the design criteria in **Section 6** of this specification.

Multi-Cell Wetland and *multi-cell pond/wetland combination* systems (Level 2 designs) are effective in moderately- to highly-urban areas where space is a premium and providing adequate surface area or grade drop is difficult. The Level 2 design options do not include any Treatment Volume (extended detention) storage or channel protection (detention) storage above the wetland cell pools. The critical design factor is the depth of temporary ponding allowed above the wetland cell pools to pass the larger design storms or if the wetland cell pools are hydraulically connected to the pond cell. A preferred design is illustrated in **Figure 13.4** and **13.5** above, with the wetland cells independent of the detention ponding, ***allowing for a greater temporary ponding depth in the pond component, while keeping the temporary storage depth to a maximum (12 inches) in the wetland***.

The *Pond/Wetland* combination design involves a wet pond cell in parallel or series with constructed wetland cells designed to convey small storms through the wetland cells while diverting (or overflowing with minimal ponding depth) the larger storm runoff into the wet pond cell, as described in the following bulleted information:

- The wet pond cell can be sized to store up to two-thirds of the Treatment Volume through a permanent pool and temporary detention. Refer to **Section 6** for detention storage design criteria. The wet pond cell will have variable water levels, but should be designed to have a minimum extended detention draw-down pool depth of 3 feet (if possible) to provide a steady supply of flow to the wetland cells).
- The wet pond cell has three primary functions: (1) pre-treatment to capture and retain heavy sediment loads or other pollutants (such as trash, oils and grease, etc.); (2) provisions for an extended supply of flow to support wetland conditions between storms; and (3) storage volume for larger storms (e.g., the channel protection and flood control design storms).
- The Pond/Wetland combination will typically include ED storage for the TV and possibly the channel protection and flooding volume within the wet pond cell. The wet pond cell ED discharge can be directed into the wetland cell (while managing the flow in the wetland cell with a maximum 12 inch ponding depth) and the larger storm discharge directed to the downstream conveyance system. The discharge from the pond cell to the wetland cell should ideally consist of a reverse slope-pipe (the design may also consist of an additional smaller pipe with a valve or other control to allow for hydrating the wetland with a trickle flow from the wet pond normal pool during dry periods).

  As an alternative, the water quality storm can be diverted into the wetland cell for treatment by using a low flow diversion sized for the Tv peak flow rate, while the larger storms are routed into the wet pond cell.
- ***No detention or extended detention is allowed within the wetland cell*** in order to prevent frequent water level fluctuations from reducing the diversity and function of wetland cover. Refer to **Section 6** for additional details.
- The wetland should be divided into sub-cells to cascade down the grade differential. Ideally, different pool depths are established with sand berms (anchored by rock at each end), back-filled coir fiber logs, or forested peninsulas (extending as wedges across 95% of the wetland width), stabilized as needed based on the design flow and velocity. The vegetative target is to ultimately achieve a 50-50 mix of emergent and forested wetland vegetation within all four cells.

SECTION 6: DESIGN CRITERIA

6.1. Sizing of Constructed Wetlands

Constructed wetlands should be designed to capture and treat the remaining Treatment Volume (T_v), and the channel protection volume (if needed) discharged from the upstream runoff reduction practices, using the accepted local or state calculation methods.

To qualify for the higher nutrient reduction rates associated with the Level 2 design, constructed wetlands must be designed with a Treatment Volume that is 50% greater than the T_v for the Level 1 design [i.e., 1.50(R_v)(A)]. Research has shown that larger constructed wetlands with longer residence times enhance nutrient removal rates. Runoff Treatment Volume credit can be taken for the following:

Constructed Wetland Basin – Level 1 design:

- The entire water volume below the normal pool (including deep pools);
- Extended detention (ED) up to 1 foot above the normal pool; and
- Any void storage within a submerged rock, sand or stone layer within the wetland.

Constructed Multi-Cell Wetland – Level 2 design (1.5 T_v):

- The entire water volume below the normal pool of each cell (including deep pools);
- Any void storage within a submerged rock, sand or stone layer within the wetland cells.

Constructed multi-cell pond/wetland combination – Level 2 (1.5 T_v):

- The entire water volume below the normal pool of the wetland cells (including deep pools);
- Any void storage within a submerged rock, sand or stone layer within the wetland cells;
- Up to 2/3 of the total required Treatment Volume when provided in a separate pond cell as follows:
  - The permanent pool volume (a minimum of 50% or 1/3 of the total T_v); and
  - The extended detention storage above the pool (a maximum of 50% or 1/3 of the total T_v). Refer to Stormwater Design Specification 14 for design details for wet ponds.

6.2. Water Balance: Sizing for Minimum Pool Depth

Initially, it is recommended that there be no minimum drainage area requirement for the system, although it may be necessary to calculate a water balance for the wet pond cell when it's CDA is less than 10 acres (Refer to Stormwater Design Specification No 14: Wet Pond).

Similarly, if the hydrology for the constructed wetland is not supplied by groundwater or dry weather flow inputs, a simple water balance calculation must be performed, using **Equation 13.1** (Hunt et al., 2007)**,** to assure the deep pools will not go completely dry during a 30 day summer drought.

Equation 13.1. The Hunt Water Balance Equation for Acceptable Water Depth in a Stormwater Wetland

$$DP = RF_m * EF * WS/WL - ET - INF - RES$$

Where:

	DP	=	Depth of pool (inches)
	RF_m	=	Monthly rainfall during drought (inches)
	EF	=	Fraction of rainfall that enters the stormwater wetland ($CDA * R_v$)
	WS/WL	=	Ratio of contributing drainage area to wetland surface area
	ET	=	Summer evapotranspiration rate (inches; assume 8)
	INF	=	Monthly infiltration loss (assume 7.2 inches @ 0.01 inch/hour)
	RES	=	Reservoir of water for a factor of safety (assume 6 inches)

Using **Equation 13.1**, setting the groundwater and (dry weather) base flow to zero and assuming a worst case summer rainfall of 0 inches, the minimum depth of the pool calculates as follows:

Depth of Pool (DP) = 0” (RF_m) – 8” (*ET*) – 7.2” (*INF)* – 6” (*RES*) = 21.2 inches

Therefore, unless there is other input, such as base flow or groundwater, the minimum depth of the pool **should be at least 22 inches** (rather than the 18” minimum depth noted in **Section 6.6**).

6.3. Geotechnical Testing

Soil borings should be taken below the proposed embankment, in the vicinity of the proposed outlet area, and in at least two locations within the planned wetland treatment area. Soil boring data is needed to (1) determine the physical characteristics of the excavated material; (2) determine its adequacy for use as structural fill or spoil; (3) provide data for the designs of outlet structures (e.g., bearing capacity and buoyancy) ; (4) determine compaction/composition needs for the embankment; (5) define the depth to groundwater and/or bedrock; and (6) evaluate potential infiltration losses (and the consequent need for a liner).

6.4. Pre-treatment Forebay

Sediment forebays are considered an integral design feature of all stormwater wetlands. A forebay must be located at every major inlet to trap sediment and preserve the capacity of the main wetland treatment cell. Other forms of pre-treatment for sheet flow and concentrated flow for minor inflow points should be designed consistent with pretreatment criteria found in Design Spec No. 9: Bioretention. The following criteria apply to forebay design:

- A major inlet is defined as an individual storm drain inlet pipe or open channel conveying runoff from least 10% of the constructed wetland’s contributing drainage area.
- The forebay consists of a separate cell in both the Level 1 and Level 2 designs, and it is formed by an acceptable barrier (e.g., an earthen berm, concrete weir, gabion baskets, etc.).
- The forebay should be a maximum of 4 feet deep (or as determined by the summer drought water balance **Equation 13.1**) near the inlet, and then transition to a 1 foot depth at the entrance to the first wetland cell.

- The forebay should be equipped with a variable width aquatic bench around the perimeter of the 4-foot depth area for safety purposes. The aquatic bench should be 4 to 6 feet wide at a depth of 1 to 2 feet below the water surface, transitioning to zero width at grade.
- The total volume of all forebays should be at least 15% of the total Treatment Volume. The relative size of individual forebays should be proportional to the percentage of the total inflow to the wetland. Similarly, any outlet protection associated with the end section or end wall should be designed according to state or local design standards.
- The bottom of the forebay may be hardened (e.g., with concrete, asphalt, or grouted riprap) to make sediment removal easier.
- The forebay should be equipped with a metered rod in the center of the pool (as measured lengthwise along the low flow water travel path) for long-term monitoring of sediment accumulation.

6.5. Conveyance and Overflow

- The slope profile within individual wetland cells should generally be flat from inlet to outlet (adjusting for microtopography). The recommended maximum elevation drop between wetland cells should be 1 foot or less.
- Since most constructed wetlands are on-line facilities, they need to be designed to safely pass the maximum design storm (e.g., the 10-year and 100-year design storms). While the ponding depths for the more frequent Treatment Volume storm (1 inch of rainfall) and channel protection storm (1-year event) are limited in order to avoid adverse impacts to the planting pallet, the overflow for the less frequent 10- and 100-year storms should likewise be carefully designed to minimize the depth of ponding. A maximum depth of 4 feet over the wetland pool is recommended).
- While many different options are available for setting the normal pool elevation, it is strongly recommended that removable flashboard risers be used, given their greater operational flexibility to adjust water levels following construction (see Hunt et al, 2007). Also, a weir can be designed to accommodate passage of the larger storm flows at relatively low ponding depths.

6.6. Internal Design Geometry

Research and experience have shown that the internal design geometry and depth zones are critical in maintaining the pollutant removal capability and plant diversity of ~~a~~ stormwater wetlands. Wetland performance is enhanced when the wetland has multiple cells, longer flowpaths, and a high ratio of surface area to volume. Whenever possible, constructed wetlands should be irregularly shaped with long, sinuous flow paths. The following design elements are *required* for stormwater wetlands:

Multiple-Cell Wetlands (Level 2 designs). When a Level 2 design is selected, the wetland should be divided into at least four internal sub-cells of different elevations: the forebay, a micro-pool outlet, and two additional cells. Cells can be formed by sand berms (anchored by rock at each end), back-filled coir fiber logs, or forested peninsulas (extending as wedges across 95% of the wetland width). The vegetative target is to ultimately achieve a 50-50 mix of emergent and forested wetland vegetation within all four cells.

The first cell (the forebay) is deeper and is used to receive runoff from the pond cell or the inflow from a pipe or open channel and distribute it as sheetflow into successive wetland cells. The surface elevation of the second cell is the normal pool elevation. It may contain a forested island or a sand wedge channel to promote flows into the third cell, which is 3 to 6 inches lower than the normal pool elevation. The purpose of the wetland cells is to create an alternating sequence of aerobic and anaerobic conditions to maximize nitrogen removal. The fourth wetland cell is located at the discharge point and serves as a micro-pool with an outlet structure or weir.

ED and Detention Ponding Depth. Where a stormwater wetland (Level 1 design) incorporates ED as a part of the T_v, the ED volume may not extend more than 1 vertical foot above the normal pool elevation. Similarly, if channel protection detention storage is provided, the total ED and detention depth must not exceed 1 foot (the T_v ED and 1-year storm detention is inclusive, not additive).

Where a Level 2 design Multi-Cell Wetland or Pond/Multi-Cell Wetland Combination is used, the ED and detention storage limits are as follows:

- Multi-Cell Wetlands (Level 2 designs) must be designed so that the T_v water level fluctuation is limited to 6 to 8 inches during the maximum water quality storm (i.e., a 1-inch rainfall event).
- The maximum water level fluctuation during the channel protection (1-year) storm should be limited to 12 inches in the wetland cells. This can be achieved by using a long weir structure capable of passing large flows at relatively low hydraulic head, or designing an upstream diversion structure to bypass the larger storms.
- The detention storage depth for the T_v and channel protection design may be up to 5 ft above the wet pond cell permanent pool.

Pool Depths. Level 1 wetland designs may have a mean pool depth greater than 1 foot. Level 2 wetland cells must have a mean pool depth less than or equal to 1 foot.

Deep Pools. Approximately 25% of the wetland Treatment Volume must be provided in at least three deeper pools – located at the inlet (forebay), center, and outlet (micropool) of the wetland – with each pool having a depth of from 18 to 48 inches. Refer to sizing based on water balance in **Section 6.2** for additional guidance on the minimum depth of the deep pools.

High Marsh Zone. Approximately 70% of the wetland surface area must exist in the high marsh zone (-6 inches to +6 inches, relative to the normal pool elevation).

Transition Zone. The low marsh zone (-6 to -18 inches below the normal pool elevation) is ***no longer an acceptable wetland zone***, and is only allowed as a short transition zone from the deeper pools to the high marsh zone. In general, this transition zone should have a maximum slope of 5H:1V (or preferably flatter) from the deep pool to the high marsh zone. It is advisable to install biodegradable erosion control fabrics or similar materials during construction to prevent erosion or slumping of this transition zone.

Flow Path. In terms of the flow path, there are two design objectives:

- The ***overall flow path through the wetland*** can be represented as the length-to-width ratio *OR* the flow path ratio (see the *Introduction to the New Virginia Stormwater Design Specifications* for diagrams and equation). These ratios must be at least 2:1 for Level 1 designs and 3:1 for Level 2 designs.
- The ***shortest flow path*** represents the distance from the closest inlet to the outlet (see the *Introduction to the New Virginia Stormwater Design Specifications*). The ratio of the shortest flow path to the overall length must be at least 0.5 for Level 1 designs and 0.8 for Level 2 designs. In some cases – due to site geometry, storm sewer infrastructure, or other factors – some inlets may not be able to meet these ratios. However, the drainage area served by these "closer" inlets should constitute no more than 20% of the total contributing drainage area.

Side Slopes. Side slopes for the wetland should generally have gradients of 4H:1V to 5H:1V. Such mild slopes promote better establishment and growth of the wetland vegetation. They also contribute to easier maintenance and a more natural appearance.

6.7. Micro-Topographic Features

Stormwater wetlands must have internal structures that create variable micro-topography, which is defined as a mix of above-pool vegetation, shallow pools, and deep pools that promote dense and diverse vegetative cover. Designers will need to incorporate at least two of the following internal design features to meet the microtopography requirements for Level 2 designs:

- Tree peninsulas, high marsh wedges or rock filter cells configured perpendicular to the flow path.
- Tree islands above the normal pool elevation and maximum extended detention zone, formed by coir fiber logs.
- Inverted root wads or large woody debris.
- Gravel diaphragm layers within high marsh zones.
- Cobble sand weirs (see Stormwater Design Specification No. 11: Wet Swales, for standard details).
- Additional deeper pools.

6.8. Maintenance Reduction Features

The following design criteria will help to avoid significant maintenance problems pertaining to constructed wetlands:

Maintenance Access. Good access is needed so crews can remove sediments, make repairs and preserve wetland treatment capacity).

- Maintenance access must be provided to the forebay, safety benches, and outlet riser area.
- Risers should be located in embankments to ensure easy access.

- Access roads must (1) be constructed of load bearing materials, (2) have a minimum width of 12 feet, and (3) possess a maximum profile grade of 15%.
- Turnaround areas may also be needed, depending on the size and configuration of the wetland.

Clogging Reduction. If the low flow orifice clogs, it can result in a rapid change in wetland water elevations that can potentially kill wetland vegetation. Therefore, designers should carefully design the flow control structure to minimize clogging, as follows:

- A minimum 3-inch diameter orifice is recommended in order to minimize clogging of an outlet or extended detention pipe when it is surface fed.. It should be noted, however, that even a 3 inch orifice will be very susceptible to clogging from floating vegetation and debris.
- Smaller openings (down to 1 inch in diameter) are permissible, using internal orifice plates within the pipe.
- All outlet pipes should be adequately protected by trash racks, half-round CMP, or reverse-sloped pipes extending to mid-depth of the micropool. Refer to guidance on low-flow orifice design in **Chapter 13** of the ***Virginia Stormwater Handbook*** (2010).

6.9. Wetland Landscaping Plan

An initial wetland landscaping plan is required for any stormwater wetland and should be jointly developed by the engineer and a wetlands expert or experienced landscape architect. The plan should outline a detailed schedule for the care, maintenance and possible reinforcement of vegetation in the wetland and its buffer for up to 10 years after the original planting. More details on preparing a wetland landscaping plan can be found throughout this specification.

The plan should outline a realistic, long-term planting strategy to establish and maintain desired wetland vegetation. The plan should indicate how wetland plants will be established within each inundation zone (e.g., wetland plants, seed-mixes, volunteer colonization, and tree and shrub stock) and whether soil amendments are needed to get plants started. At a minimum, the plan should contain the following:

- Plan view(s) with topography at a contour interval of no more than 1 foot and spot elevations throughout the cell showing the wetland configuration, different planting zones (e.g., high marsh, deep water, upland), microtopography, grades, site preparation, and construction sequence.
- A plant schedule and planting plan specifying emergent, perennial, shrub and tree species, quantity of each species, stock size, type of root stock to be installed, and spacing. To the degree possible, the species list for the constructed wetland should contain plants found in similar local wetlands.

The local regulatory authority will usually establish any more specific vegetative goals to achieve in the wetland landscaping plan. The following general guidance is provided:

- ***Use Native Species Where Possible.*** **Table 13.3** provides a list of common native shrub and tree species and **Table 13.4** provides a list of common native emergent, submergent and perimeter plant species, all of which have proven to do well in stormwater wetlands in the mid-Atlantic region and are generally available from most commercial nurseries (for a list of some of these nurseries, see **Table 13.5**). Other native species can be used that appear in state-wide plant lists The use of native species is strongly encouraged, but in some cases, non-native ornamental species may be added as long as they are not invasive. Invasive species such as cattails, *Phragmites* and purple loosestrife should never be planted.

- ***Match Plants to Inundation Zones.*** The various plant species shown in **Tables 13.3 and 13.4** should be matched to the appropriate inundation zone. The first four inundation zones are are particularly applicable to stormwater wetlands, as follows:
    - **Zone 1**: -6 inches to -12 below the normal pool elevation
    - **Zone 2**: -6 inches to the normal pool elevation)
    - **Zone 3**: From the normal pool elevation to + 12 inches above it)
    - **Zone 4**: +12 inches to + 36 inches above the normal pool elevation (i.e., above ED Zone)

  (Note that the Low Marsh Zone (-6 inches to -18 inches below the normal pool elevation) has been dropped since experience has shown that few emergent wetland plants flourish in this deeper zone.)
- ***Aggressive Colonizers.*** To add diversity to the wetland, 5 to 7 species of emergent wetland plants should be planted, using at least four emergent species designated as aggressive colonizers (shown in bold in **Table 13.4**). No more than 25% of the high marsh wetland surface area needs to be planted. If the appropriate planting depths are achieved, the entire wetland should be colonized within three years. Individual plants should be planted 18 inches on center within each single species “cluster”.

Table 13.3. Popular, Versatile and Available Native Trees and Shrubs for Constructed Wetlands

Shrubs		Trees	
Common & *Scientific* Names	**Zone**	**Common & *Scientific* Names**	**Zone**
Button Bush *(Cephalanthus occidentalis)*	2, 3	Atlantic White Cedar *(Charnaecyparis thyoides)*	2, 3
Common Winterberry *(Ilex verticillatta)*	3, 4	Bald Cypress *(Taxodium distichum)*	2, 3
Elderberry *(Sambucus canadensis)*	3	Black Willow *(Salix nigra)*	3, 4
Indigo Bush *(Amorpha fruticosa)*	3	Box Elder *(Acer Negundo)*	2, 3
Inkberry *(Ilex glabra)*	2, 3	Green Ash *(Fraxinus pennsylvanica)*	3, 4
Smooth Alder *(Alnus serrulata)*	2, 3	Grey Birch *(Betula populifolia)*	3, 4
Spicebush *(Lindera benzoin)*	3, 4	Red Maple *(Acer rubrum)*	3, 4
Swamp Azalea *(Azalea viscosum)*	2, 3	River Birch *(Betula nigra)*	3, 4
Swamp Rose *(Rosa palustris)*	2, 3	Swamp Tupelo *(Nyssa biflora)*	2, 3
Sweet Pepperbush *(Clethra ainifolia)*	2, 3	Sweetbay Magnolia *(Magnolia virginiana)*	3, 4
		Sweetgum *(Liquidambar styraciflua)*	3, 4
		Sycamore *(Platanus occidentalis)*	3, 4
		Water Oak *(Quercus nigra)*	3, 4
		Willow Oak *(Quercus phellos)*	3,4
Zone 1: -6 to -12 ***OR*** -18 inches below the normal pool elevation Zone 2: -6 inches to the normal pool elevation Zone 3: From the normal pool elevation to +12 inches Zone 4: +12 to +36 inches; above ED zone			

Table 13.4. Popular, Versatile and Available Native Emergent and Submergent Vegetation for Constructed Wetlands

Plant	Zone	Form	Inundation Tolerance	Wildlife Value	Notes
Arrow Arum *(Peltandra virginica)*	2	Emergent	Up to 1 ft.	High; berries are eaten by wood ducks	Full sun to partial shade
Broad-Leaf Arrowhead (Duck Potato) ***(Saggitaria latifolia)***	2	Emergent	Up to 1 ft.	Moderate; tubers and seeds eaten by ducks	Aggressive colonizer
Blueflag Iris* *(Iris versicolor)*	2, 3	Emergent	Up to 6 in.	Limited	Full sun (to flower) to partial shade
Broomsedge *(Andropogon virginianus)*	2, 3	Perimeter	Up to 3 in.	High; songbirds and browsers; winter food and cover	Tolerant of fluctuating water levels and partial shade
Bulltongue Arrowhead ***(Sagittaria lancifolia)***	2, 3	Emergent	0-24 in	Waterfowl, small mammals	Full sun to partial shade
Burreed ***(Sparganium americanum)***	2, 3	Emergent	0-6	Waterfowl, small mammals	Full sun to partial shad
Cardinal Flower * *(Lobelia cardinalis)*	3	Perimeter	Periodic inundation	Attracts hummingbirds	Full sun to partial shade
Common Rush ***(Juncus spp.)***	2, 3	Emergent	Up to 12 in.	Moderate; small mammals, waterfowl, songbirds	Full sun to partial shade
Common Three Square ***(Scipus pungens)***	2	Emergent	Up to 6 in.	High; seeds, cover, waterfowl, songbirds	Fast colonizer; can tolerate periods of dryness; ull sun; high metal removal
Duckweed (*Lemna sp.*	1, 2	Submergent / Emergent	Yes	High; food for waterfowl and fish	May biomagnify metals beyond concentrations found in the water
Joe Pye Weed *(Eupatorium purpureum)*	2, 3	Emergent	Drier than other Joe-Pye Weeds; dry to moist areas; periodic inundation	Butterflies, songbirds, insects	Tolerates all light conditions
Lizard's Tail ***(Saururus cernus)***	2	Emergent	Up to 1 ft.	Low; except for wood ducks	Rapid growth; shade-tolerant
Marsh Hibiscus *(Hibiscus moscheutos)*	2, 3	Emergent	Up to 3 in.	Low; nectar	Full sun; can tolerate periodic dryness
Pickerelweed ***(Pontederia cordata)***	2, 3	Emergent	Up to 1 ft.	Moderate; ducks, nectar for butterflies	Full sun to partial shade
Pond Weed *(Potamogeton pectinatus)*	1	Submergent	Yes	Extremely high; waterfowl, marsh and shore birds	Removes heavy metals from the water
Rice Cutgrass *(Leersia oryzoides)*	2, 3	Emergent	Up to 3 in.	High; food and cover	Prefers full sun, although tolerant of shade; shoreline stabilization
Sedges ***(Carex spp.)***	2, 3	Emergent	Up to 3 in.	High; waterfowl, songbirds	Wetland and upland species
Softstem Bulrush ***(Scipus validus)***	2, 3	Emergent	Up to 2 ft.	Moderate; good cover and food	Full sun; aggressive colonizer; high pollutant removal

Plant	Zone	Form	Inundation Tolerance	Wildlife Value	Notes
Smartweed ***(Polygonum spp.)***	2	Emergent	Up to 1 ft.	High; waterfowl, songbirds; seeds and cover	Fast colonizer; avoid weedy aliens, such as P. Perfoliatum
Spatterdock ***(Nuphar luteum)***	2	Emergent	Up to 1.5 ft.	Moderate for food, but High for cover	Fast colonizer; tolerant of varying water levels
Switchgrass *(Panicum virgatum)*	2, 3, 4	Perimeter	Up to 3 in.	High; seeds, cover; waterfowl, songbirds	Tolerates wet/dry conditions
Sweet Flag * *(Acorus calamus)*	2, 3	Perimeter	Up to 3 in.	Low; tolerant of dry periods	Tolerates acidic conditions; not a rapid colonizer
Waterweed *(Elodea canadensis)*	1	Submergent	Yes	Low	Good water oxygenator; high nutrient, copper, manganese and chromium removal
Wild celery *(Valisneria americana)*	1	Submergent	Yes	High; food for waterfowl; habitat for fish and invertebrates	Tolerant of murkey water and high nutrient loads
Wild Rice *(Zizania aquatica)*	2	Emergent	Up to 1 ft.	High; food, birds	Prefers full sun
Woolgrass ***(Scirpus cyperinus)***	3, 4	Emergent	yes	High: waterfowl, small mammals	Fresh tidal and nontidal, swamps, forested wetlands, meadows, ditches

Zone 1: -6 to -12 ***OR*** -18 inches below the normal pool elevation
Zone 2: -6 inches to the normal pool elevation
Zone 3: From the normal pool elevation to +12 inches
Zone 4: +12 to +36 inches; above ED zone
* Not a major colonizer, but adds color (Aggressive colonizers are shown in **bold** type)

- ***Suitable Tree Species.*** The major shift in stormwater wetland design is to integrate trees and shrubs into the design, in tree islands, peninsulas, and fringe buffer areas. Deeper-rooted trees and shrubs that can extend to the stormwater wetland's local water table are important for creating a mixed wetland community. **Table 13.3** above presents some recommended tree and shrub species in the mid-Atlantic region for different inundation zones. A good planting strategy includes varying the size and age of the plant stock to promote a diverse structure. Using locally grown container or bare root stock is usually the most successful approach, if planting in the Spring. It is recommended that buffer planting areas be over-planted with a small stock of fast growing successional species to achieve quick canopy closure and shade out invasive plant species. Trees may be planted in clusters to share rooting space on compacted wetland side-slopes. Planting holes should be amended with compost (a 2:1 ratio of loose soil to compost) prior to planting.
- ***Pre- and Post-Nursery Care.*** Plants should be kept in containers of water or moist coverings to protect their root systems and keep them moist when in transporting them to the planting location. As much as six to nine months of lead time may be needed to fill orders for wetland plant stock from aquatic plant nurseries (**Table 13.5**).

Table 13.5. Native Nursery Sources in the Chesapeake Bay

State	Nursery Name	Nursery Web Site
MD	American Native Plants **W**	www.americannativeplantsonline.com
MD	Ayton State Tree Nursery	www.dnr.state.md.us/forests/nursery
MD	Chesapeake Natives. Inc.	www.chesapeakenatives.org
MD	Clear Ridge Nursery, Inc. **W**	www.clearridgenursery.com
MD	Environmental Concern **W**	www.wetland.org
MD	Lower Marlboro Nursery **W**	www.lowermarlboronursery.com
MD	Homestead Gardens	www.homesteadgardens.com
NJ/VA	Pinelands Nursery **W**	www.pinelandsnursery.com
PA	Appalachian Nursery	www.appnursery.com
PA	Octoraro Native Plant Nursery	www.OCTORARO.com
PA	Redbud Native Plant Nursery **W**	www.redbudnativeplantnursery.com
PA	New Moon Nursery, Inc. **W**	www.newmoonnursery.com
PA	Sylva Native Nursery/Seed Co. **W**	www.sylvanative.com
VA	Lancaster Farms, Inc.	www.lancasterfarms.com
VA	Nature by Design **W**	www.nature-by-design.com

Notes:
This is a partial list of available nurseries and does NOT constitute an endorsement of them. For updated lists of native plant nurseries, consult the following sources:
Virginia Native Plant Society www.vnps.org
Maryland Native Plant Society www.mdflora.org
Pennsylvania Native Plant Society www.pawildflowers.org
Delaware Native Plant Society www.delawarenativeplants.org

W: indicates that nursery has an inventory of emergent wetland species

6.10. Constructed Wetland Material Specifications

Wetlands are generally constructed with materials obtained on-site, except for the plant materials, inflow and outflow devices (e.g., piping and riser materials), possibly stone for inlet and outlet stabilization, and filter fabric for lining banks or berms. The basic material specifications for earthen embankments, principal spillways, vegetated emergency spillways and sediment forebays shall be as specified in **Appendices A-D** of the *Introduction to the New Virginia Stormwater Design Specifications*, as posted on the Virginia Stormwater BMP Clearinghouse web site, at the following URL:

http://www.vwrrc.vt.edu/swc/NonProprietaryBMPs.html

Plant stock should be nursery grown, unless otherwise approved by the local regulatory authority, and should be healthy and vigorous native species free from defects, decay, disfiguring roots, sun-scald, injuries, abrasions, diseases, insects, pests, and all forms of infestations or objectionable disfigurements, as determined by the local regulatory authority.

SECTION 7: REGIONAL & SPECIAL CASE DESIGN ADAPTATIONS

7.1. Karst Terrain

Even shallow pools in karst terrain can increase the risk of sinkhole formation and groundwater contamination. Designers should always conduct geotechnical investigations in karst terrain to assess this risk during the project planning stage. If constructed wetlands are employed in karst terrain, the designer must:

- Employ an impermeable liner that meets the requirements outlined in **Table 13.6**.
- Maintain at least 3 feet of vertical separation from the underlying karst layer.
- Shallow, linear and multiple cell wetland configurations are preferred.
- Deeper basin configurations, such as the pond/wetland system and the ED wetland have limited application in karst terrain.

Table 13.6. Required Groundwater Protection Liners for Ponds in Karst Terrain

Situation	Criteria
Not Excavated to Bedrock	24 inches of soil with a maximum hydraulic conductivity of 1 x 10^{-5} cm/sec
Excavated to or near Bedrock	24 inches of clay[1] with maximum hydraulic conductivity of 1 x 10^{-6} cm/sec
Excavated to Bedrock within wellhead protection area, in recharge are for domestic well or spring, or in known faulted or folded area	24 inches of clay[1] with maximum hydraulic conductivity of 1 x 10^{-7} cm/sec and a synthetic liner with a minimum thickness of 60 mil.

[1] Plasticity Index of Clay: Not less than 15% (ASTM D-423/424)
Liquid Limit of Clay: Not less than 30% (ASTM D-2216)
Clay Particles Passing: Not less than 30% (ASTM D-422)
Clay Compaction: 95% of standard proctor density (ASTM D-2216)

Source: WVDEP, 2006 and VA Stormwater Management Handbook, 1999

7.2. Coastal Plain

Constructed wetlands are an ideal practice for the flat terrain, low hydraulic head and high water table conditions found at many coastal plain development sites. The following design adaptations can make them work more effectively in coastal plain settings:

- Shallow, linear and multiple-cell wetland configurations are preferred.
- It is acceptable to excavate up to 6 inches below the seasonally high groundwater table to provide the requisite hydrology for wetland planting zones, and up to 3 feet below for micropools, forebays and other deep pool features.
- The volume below the seasonably high groundwater table is acceptable for the Treatment Volume, as long as the other primary geometric and design requirements for the wetland are met (e.g., flow path and microtopography).
- Plant selection should focus on species that are wet-footed and can tolerate some salinity.

- A greater range of coastal plain tree species can tolerate periodic inundation, so designers should consider creating forested wetlands, using species such as Atlantic White Cedar, Bald Cypress and Swamp Tupelo.
- The use of flashboard risers is recommended to control or adjust water elevations in wetlands constructed on flat terrain.
- The regenerative conveyance system is particularly suited for coastal plain situations, where there is a significant drop in elevation from the channel to the outfall location (see Stormwater Design Specification #11: Wet Swales).

7.3. Steep Terrain – Regenerative Conveyance Systems

Constructed wetlands are not an effective practice at development sites with steep terrain. Some adjustment can be made by terracing wetland cells in a linear manner as with Regenerative Conveyance Systems (RSC).

Regenerative stormwater conveyance (RSC) systems are open-channel, sand seepage filtering systems that utilize a series of shallow aquatic pools, riffle weir grade controls, native vegetation and underlying sand channel to treat and safely detain and convey storm flow, and convert stormwater to groundwater via infiltration at coastal plain outfalls and other areas where grades make traditional practices difficult to implement. RSC systems combine features and treatment benefits of swales, infiltration, filtering and wetland practices. In addition, they are designed to convey flows associated with extreme floods (i.e., 100 year return frequency event) in a non-erosive manner, which results in a reduction of channel erosion impacts commonly encountered at conventional stormwater outfalls and headwater stream channels.

RCS systems are referred to as Step Pool Storm Conveyance (SPSC) channels in Ann Arundel County, MD where systems have been installed and observed. The physical characteristics of the SPSC channel are best characterized by the Rosgen A or B stream classification types, where "bedform occurs as a step/pool cascading channel which often stores large amounts of sediment in the pools associated with debris dams" (Rosgen, 1996). Due to their ability to safely convey large flood events, RSC systems do not require flow splitters to divert smaller events for water quality treatment, and reduce the need for storm drain infrastructure in the conveyance system.

These structures feature surface/subsurface runoff storage seams and an energy dissipation design that is aimed at attenuating the flow to a desired level through energy and hydraulic power equivalency principles. RSC systems have the added benefit of creating dynamic and diverse ecosystems for a range of plants, animals, amphibians and insects. These ecosystems enhance pollutant uptake and assimilation and provide a natural and native aesthetic at sites. RSC systems are unique in that they can be located on the front or tail end of a treatment system and still provide water quality and groundwater recharge benefits. Where located on the front end of a treatment train, they provide water quality, groundwater recharge, and channel protection, while also providing non-erosive flow conveyance that delivers flow to the stormwater quantity practice - a constructed wetland, wet pond, ED Pond, or combination.

The Ann Arundel County design specification can be found at:
http://www.aacounty.org/DPW/Watershed/StepPoolStormConveyance.cfm

7.4. Cold Climate and Winter Performance

Wetland performance decreases when snowmelt runoff delivers high pollutant loads. Shallow constructed wetlands can freeze in the winter, which allows runoff to flow over the ice layer and exit without treatment. Inlet and outlet structures close to the surface may also freeze, further diminishing wetland performance. Salt loadings are higher in cold climates due to winter road maintenance. High chloride inputs have a detrimental effect on native wetland vegetation and can shift the wetland plant composition to more salt-tolerant but less desirable species, such as cattails (Wright *et al*., 2006). Designers should choose salt-tolerant species when crafting their planting plans and consider specifying reduced salt applications in the contributing drainage area, when they actually have control of this. The following design adjustments are recommended for stormwater wetlands installed in higher elevations and colder climates.

- Treat larger runoff volumes in the spring by adopting seasonal operation of the permanent pool (see MSSC, 2005).
- Plant salt-tolerant wetland vegetation.
- Do not submerge inlet pipes and provide a minimum 1% pipe slope to discourage ice formation.
- Locate low flow orifices so they withdraw at least 6 inches below the typical ice layer.
- Angle trash racks to prevent ice formation.
- Over-size the riser and weir structures to avoid ice formation and freezing pipes.
- If road sanding is prevalent in the contributing drainage area, increase the forebay size to accommodate additional sediment loading.

7.5. Linear Highway Sites

Wet swales, linear wetland cells and regenerative conveyance systems are particularly well suited and considered preferred practices to treat runoff within open channels located in the highway right of way.

SECTION 8: CONSTRUCTION

The construction sequence for stormwater wetlands depends on site conditions, design complexity, and the size and configuration of the proposed facility. The following two-stage construction sequence is recommended for installing an on-line wetland facility and establishing vigorous plant cover.

8.1. Stage 1 Construction Sequence: Wetland Facility Construction

Step 1: Stabilize Drainage Area. Stormwater wetlands should only be constructed after the contributing drainage area to the wetland is completely stabilized. If the proposed wetland site will be used as a sediment trap or basin during the construction phase, the construction notes should clearly indicate that the facility will be de-watered, dredged and re-graded to design dimensions after the original site construction is complete.

Step 2: Assemble Construction Materials on-site, make sure they meet design specifications, and prepare any staging areas.

Step 3: Clear and Strip the project area to the desired sub-grade.

Step 4: Install Erosion and Sediment (E&S) Controls prior to construction, including temporary dewatering devices, sediment basins, and stormwater diversion practices. All areas surrounding the wetland that are graded or denuded during construction of the wetland are to be planted with turf grass, native plant materials or other approved methods of soil stabilization. Grass sod is preferred over seed to reduce seed colonization of the wetland. During construction the wetland must be separated from the contributing drainage area so that no sediment flows into the wetland areas. In some cases, a phased or staged E&S Control plan may be necessary to divert flow around the stormwater wetland area until installation and stabilization are complete.

Step 5: Excavate the Core Trench for the Embankment and Install the Spillway Pipe.

Step 6: Install the Riser or Outflow Structure and ensure that the top invert of the overflow weir is constructed level and at the proper design elevation (flashboard risers are strongly recommended by Hunt et al, 2007).

Step 7: Construct the Embankment and any Internal Berms in 8 to 12-inch lifts and compacted with appropriate equipment.

Step 8: Excavate/Grade until the appropriate elevation and desired contours are achieved for the bottom and side slopes of the wetland. This is normally done by "roughing up" the interim elevations with a skid loader or other similar equipment to achieve the desired topography across the wetland. Spot surveys should be made to ensure that the interim elevations are 3 to 6 inches below the final elevations for the wetland.

Step 9: Install Micro-Topographic Features and Soil Amendments within wetland area. Since most stormwater wetlands are excavated to deep sub-soils, they often lack the nutrients and organic matter needed to support vigorous growth of wetland plants. It is therefore essential to add sand, compost, topsoil or wetland mulch to all depth zones in the wetland. The importance of soil amendments in excavated wetlands cannot be over-emphasized; poor survival and future wetland coverage are likely if soil amendments are not added (Bowers, 1992). The planting soil should be a high organic content loam or sandy loam, placed by mechanical methods, and spread by hand. Planting soil depth ~~of~~ should be at least 4 inches for shallow wetlands. No machinery should be allowed to traverse over the planting soil during or after construction. Planting soil should be tamped as directed in the design specifications, but it should not be overly compacted. After the planting soil is placed, it should be saturated and allowed to settle for at least one week prior to installation of plant materials.

Step 10: Construct the Emergency Spillway in cut or structurally stabilized soils.

Step 11: Install Outlet Pipes, including the downstream rip-rap apron protection.

Step 12: Stabilize Exposed Soils with temporary seed mixtures appropriate for a wetland environment. All wetland features above the normal pool elevation should be temporarily stabilized by hydro-seeding or seeding over straw.

8.2. Stage 2 Construction Sequence: Establishing the Wetland Vegetation

Step 13: Finalize the Wetland Landscaping Plan. At this stage the engineer, landscape architect, and wetland expert work jointly to refine the initial wetland landscaping plan *after* the stormwater wetland has been constructed. Several weeks of standing time is needed so that the designer can more precisely predict the following two things:

- Where the inundation zones are located in and around the wetland; and
- Whether the final grade and wetland microtopography will persist over time.

This allows the designer to select appropriate species and additional soil amendments, based on field confirmation of soils properties and the actual depths and inundation frequencies occurring within the wetland.

Step 14: Open Up the Wetland Connection. Once the final grades are attained, the pond and/or contributing drainage area connection should be opened to allow the wetland cell to fill up to the normal pool elevation. Gradually inundate the wetland erosion of unplanted features. Inundation must occur in stages so that deep pool and high marsh plant materials can be placed effectively and safely. Wetland planting areas should be at least partially inundated during planting to promote plant survivability.

Step 15: Measure and Stake Planting Depths at the onset of the planting season. Depths in the wetland should be measured to the nearest inch to confirm the original planting depths of the planting zone. At this time, it may be necessary to modify the plan to reflect altered depths or a change in the availability of wetland plant stock. Surveyed planting zones should be marked on the as-built or design plan, and their locations should also be identified in the field, using stakes or flags.

Step 16: Propagate the Stormwater Wetland. Three techniques are used in combination to propagate the emergent community over the wetland bed:

1. *Initial Planting of Container-Grown Wetland Plant Stock.* The transplanting window extends from early April to mid-June. Planting after these dates is quite chancy, since emergent wetland plants need a full growing season to build the root reserves needed to get through the winter. If at all possible, the plants should be ordered at least 6 months in advance to ensure the availability and on-time delivery of desired species.

2. *Broadcasting Wetland Seed Mixes*. The higher wetland elevations should be established by broadcasting wetland seed mixes to establish diverse emergent wetlands. Seeding of switchgrass or wetland seed mixes as a ground cover is recommended for all zones above 3 inches below the normal pool elevation. Hand broadcasting or hydroseeding can be used to spread seed, depending on the size of the wetland cell.

3. *Allowing "Volunteer Wetland Plants to Establish on Their Own*. The remaining areas of the stormwater wetland will eventually (within 3 to 5 years) be colonized by volunteer species from upstream or the forest buffer.

Step 17: Install Goose Protection to Protect Newly Planted or Newly Growing Vegetation. This is particularly critical for newly established emergents and herbacacious plants, as predation by Canada geese can quickly dessimate wetland vegetation. Goose protection can consist of netting, webbing, or string installed in a criss-cross pattern over the surface area of the wetland, above the level of the emergent plants.

Step 17: Plant the Wetland Fringe and Buffer Area. This zone generally extends from 1 to 3 feet above the normal pool elevation (from the shoreline fringe to about half of the maximum water surface elevation for the 2-year storm). Consequently, plants in this zone are infrequently inundated (5 to 10 times per year), and must be able to tolerate both wet and dry periods.

8.3. Construction Inspection

Construction inspections are critical to ensure that stormwater wetlands are properly constructed and established. Multiple site visits and inspections are recommended during the following stages of the wetland construction process:

- Pre-construction meeting
- Initial site preparation (including installation of project E&S controls)
- Excavation/Grading (e.g., interim/final elevations)
- Wetland installation (e.g., microtopography, soil amendments and staking of planting zones)
- Planting Phase (with an experienced landscape architect or wetland expert)
- Final Inspection (develop a punch list for facility acceptance)

A construction phase inspection checklist for Constructed Wetlands can be accessed at the CWP website at:

http://www.cwp.org/Resource_Library/Controlling_Runoff_and_Discharges/sm.htm
(scroll to Tool6: Plan Review, BMP Construction, and Maintenance Checklists)

SECTION 9: MAINTENANCE

9.1. Maintenance Agreements

Section 4 VAC 50-60-124 of the regulations specifies the circumstances under which a maintenance agreement must be executed between the owner and the local program. This section sets forth inspection requirements, compliance procedures if maintenance is neglected, notification of the local program upon transfer of ownership, and right-of-entry for local program personnel.

It is also recommended that the maintenance agreement include a list of qualified contractors that can perform inspection or maintenance services, as well as contact information for owners to get local or state assistance to solve common nuisance problems, such as mosquito control, geese, invasive plants, vegetative management, and beaver removal. The CWP *Pond and Wetland Maintenance Guidebook* (2004) provides some excellent templates of how to respond to these problems.

9.2. First Year Maintenance Operations

Successful establishment of constructed wetland areas requires that the following tasks be undertaken in the first two years:

Initial Inspections. During the first 6 months following construction, the site should be inspected at least twice after storm events that exceed 1/2 inch of rainfall.

Spot Reseeding. Inspectors should look for bare or eroding areas in the contributing drainage area or around the wetland buffer, and make sure they are immediately stabilized with grass cover.

Watering. Trees planted in the buffer and on wetland islands and peninsulas need watering during the first growing season. In general, consider watering every three days for first month, and then weekly during the first growing season (April - October), depending on rainfall.

Reinforcement Plantings. Regardless of the care taken during the initial planting of the wetland and buffer, it is probable that some areas will remain unvegetated and some species will not survive. Poor survival can result from many unforeseen factors, such as predation, poor quality plant stock, water level changes, drought. Thus, it is advisable to budget for an additional round of reinforcement planting after one or two growing seasons. Construction contracts should include a care and replacement warranty extending at least two growing seasons after initial planting, to selectively replant portions of the wetland that fail to fill in or survive.

9.3. Inspections and Ongoing Maintenance

Ideally, maintenance of constructed wetlands should be driven by annual inspections that evaluate the condition and performance of the wetland, including the following:

- Measure sediment accumulation levels in forebays and micropools.
- Monitor the growth and survival of emergent wetlands and tree/shrub species. Record the species and approximate coverage, and note the presence of any invasive plant species.
- Inspect the condition of stormwater inlets to the wetland for material damage, erosion or undercutting.
- Inspect upstream and downstream banks for evidence of sloughing, animal burrows, boggy areas, woody growth or gully erosion that may undermine embankment integrity.
- Inspect the wetland outfall channel for erosion, undercutting, rip-rap displacement, woody growth, etc.
- Inspect the condition of the principal spillway and riser for evidence of spalling, joint failure, leakage, corrosion, etc.

- Inspect the condition of all trash racks, reverse-sloped pipes, and flashboard risers for evidence of clogging, leakage, debris accumulation, etc.
- Inspect maintenance access to ensure it is free of woody vegetation, and check to see whether valves, manholes and locks can be opened or operated.
- Inspect internal and external side slopes of the wetland for evidence of sparse vegetative cover, erosion, or slumping, and make needed repairs immediately.
- Cleanups should be scheduled at least once a year to remove trash, debris and floatables.

Based on inspection results, specific maintenance tasks will be triggered. Example maintenance inspection checklists for Constructed Wetlands can be accessed in Appendix C of Chapter 9 of the *Virginia Stormwater Management Handbook* (2010) or at the CWP website at:

http://www.cwp.org/Resource_Library/Controlling_Runoff_and_Discharges/sm.htm
(scroll to Tool6: Plan Review, BMP Construction, and Maintenance Checklists)

A more detailed maintenance inspection form is also available from Appendix B of CWP's *Stormwater Pond and Wetland Maintenance Guidebook* (2004).

Managing vegetation is an important ongoing maintenance task at every constructed wetland and for each inundation zone. Following the design criteria above should result in a reduced need for regular mowing of the embankment and access roads. Vegetation within the wetland, however, will require some annual maintenance.

9.4. Non-Routine Maintenance

Sediment Removal. Frequent sediment removal from the forebay is essential to maintain the function and performance of a constructed wetland. Maintenance plans should schedule cleanouts approximately every 5 years, or when inspections indicate that 50% of the forebay sediment storage capacity has been filled. The designer should also check to see whether removed sediments can be spoiled on-site or must be hauled away. Sediments excavated from constructed wetlands are not usually considered toxic or hazardous. They can be safely disposed of by either land application or land filling.

Control Invasive Species. Designers should expect significant changes in wetland species composition to occur over time. Inspections should carefully track changes in wetland plant species distribution over time. Invasive plants should be dealt with as soon as they begin to colonize the wetland. As a general rule, control of undesirable invasive species (e.g., cattails and *Phragmites*) should commence when their coverage exceeds more than 15% of a wetland cell area. Although the application of herbicides is not recommended, some types (e.g., Glyphosate) have been used to control cattails with some success. Extended periods of dewatering may also work, since early manual removal provides only short-term relief from invasive species. While it is difficult to exclude invasive species completely from stormwater wetlands, their ability to take over the entire wetland can be reduced if the designer creates a wide range of depth zones and a complex internal structure within the wetland.

Thinning and Harvesting of Woody Growth. Thinning or harvesting of excess forest growth may be periodically needed to guide the forested wetland into a more mature state. Vegetation may need to be harvested periodically if the constructed wetland becomes overgrown. Thinning or harvesting operations should be scheduled to occur approximately 5 and 10 years after the initial wetland construction. Removal of woody species on or near the embankment and maintenance access areas should be conducted every 2 years.

SECTION 10: COMMUNITY & ENVIRONMENTAL CONCERNS

Constructed wetlands can generate the following community and environmental concerns that may need to be addressed during design.

Aesthetics and Habitat. Constructed wetlands can create wildlife habitat and can also become an attractive community feature. Designers should think carefully about how the the wetland plant community will evolve over time, since the future plant community seldom resembles the one initially planted.

Existing Forests. Given the large footprint of a constructed wetland, there is a strong chance that the construction process may result in extensive tree clearing. The designer should preserve mature trees during the facility layout, and he/she may consider creating a wooded wetland (see Cappiella *et al*., 2006b).

Stream Warming Risk. Constructed wetlands have a moderate risk of causing stream warming. If a constructed wetland will discharge to temperature-sensitive waters, the designer should consider using the wooded wetland design to shade the water, and any extended detention storage should be released in less than 12 hours.

Safety Risk. Constructed wetlands are safer than other types of ponds, although forebays and micropools should be designed with aquatic benches to reduce safety risks.

Mosquito Risk. Mosquito control can be a concern for stormwater wetlands if they are under-sized or have a small contributing drainage area. Few mosquito problems are reported for well designed, properly-sized and frequently-maintained constructed wetlands; however, no design can eliminate them completely. Simple precautions can be taken to minimize mosquito breeding habitat within constructed wetlands (e.g., constant inflows, benches that create habitat for natural predators, and constant pool elevations – see Walton 2003 and MSSC, 2005).

SECTION 11: REFERENCES

Cappiella, K., T. Schueler, J. Tasillo and T. Wright. 2005. "Adapting Watershed Tools to Protect Wetlands." *Wetlands and Watersheds Article No. 3.* Center for Watershed Protection. Ellicott City, MD.

Cappiella, K., L. Fraley-McNeal, M. Novotney and T. Schueler. 2008. "The Next Generation of Stormwater Wetlands." *Wetlands and Watersheds Article No. 5.* Center for Watershed Protection. Ellicott City, MD.

Center for Watershed Protection (CWP). 2004. *Pond and Wetland Maintenance Guidebook*. Ellicott City, MD.

CWP. 2007. *National Pollutant Removal Performance Database Version 3.0*. Center for Watershed Protection, Ellicott City, MD.

Claytor, R. and T. Schueler. 1996. *Design of Stormwater Filtering Systems*. Center for Watershed Protection. Ellicott City, MD.

Hirschman, D. and J. Kosco. 2008. *Managing Stormwater in Your Community: A Guide for Building an Effective Post-Construction Program*. EPA Publication 833-R-08-001, Tetra-tech, Inc. and the Center for Watershed Protection. Ellicott City, MD.

Hunt, W., M. Burchell, J. Wright and K. Bass. 2007. "Stormwater Wetland Design Update: Zones, Vegetation, Soil and Outlet Guidance." *Urban Waterways*. North Carolina State Cooperative Extension Service. Raliegh, NC.

Maryland Department of Environment (MDE). 2000. *Maryland Stormwater Design Manual*. Baltimore, MD.

Schueler, T. 1992. *Design of Stormwater Wetland Systems: Guidelines for Creating Diverse and Effective Stormwater Wetlands in the Mid-Atlantic Region*. Metropolitan Washington Council of Governments. Washington, DC.

Schueler, T., D. Hirschman, M. Novotney and J. Zielinski. 2007. *Urban Stormwater Retrofit Practices*. Manual 3 in the Urban Subwatershed Restoration Manual Series. Center for Watershed Protection, Ellicott City, MD.

Schueler, T. 2008. Technical Support for the Baywide Runoff Reduction Method. Chesapeake Stormwater Network. Baltimore, MD. www.chesapeakestormwater.net

Shaw, D. and R. Schmidt. 2003. *Plants for Stormwater Design: Species Selection for the Upper Midwest*. Minnesota Pollution Control Agency. St. Paul, MN.

Virginia Stormwater Management Handbook. 1999. *Volumes 1 and 2*. Richmond, VA.

Wright, T., J. Tomlinson, T. Schueler, Karen Cappiella, A. Kitchell and D. Hirschman. 2006. "Direct and Indirect Impacts of Land Development on Wetland Quality." *Wetlands and Watersheds Article No. 1*. Center for Watershed Protection. Ellicott City, MD.

VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 14

WET POND

VERSION 1.9
March 1, 2011

SECTION 1: DESCRIPTION

Wet ponds consist of a permanent pool of standing water that promotes a better environment for gravitational settling, biological uptake and microbial activity. Runoff from each new storm enters the pond and partially displaces pool water from previous storms. The pool also acts as a barrier to re-suspension of sediments and other pollutants deposited during prior storms. When sized properly, wet ponds have a residence time that ranges from many days to several weeks, which allows numerous pollutant removal mechanisms to operate. Wet ponds can also provide extended detention (ED) above the permanent pool to help meet channel protection requirements (see **Table 14.1**).

Designers should note that a wet pond is the final element in the roof-to-stream runoff reduction sequence, so one **should be considered *only* if there is remaining Treatment Volume or Channel Protection Volume to manage after all other upland runoff reduction options have been considered and properly credited.** Wet ponds may be allowed in certain coastal plain situations where the water table is within 3 feet of the ground surface.

SECTION 2: PERFORMANCE

Table 14.1. Summary of Stormwater Functions Provided by Wet Ponds

Stormwater Function	Level 1 Design	Level 2 Design
Annual Runoff Volume Reduction (RR) [1]	0%	0%
Total Phosphorus (TP) EMC Reduction[2] **by BMP Treatment Process**	50% (45%) [3]	75% (65%) [3]
Total Phosphorus (TP) Mass Load Removal	50% (45%) [3]	75% (65%) [3]
Total Nitrogen (TN) EMC Reduction[2] **by BMP Treatment Process**	30% (20%) [3]	40% (30%) [3]
Total Nitrogen (TN) Mass Load Removal	30% (20%) [3]	40% (30%) [3]
Channel Protection	Yes; detention storage can be provided above the permanent pool.	
Flood Mitigation	Yes; flood control storage can be provided above the permanent pool.	

[1] Runoff Reduction rates for ponds used for year round irrigation can be determined through a water budget computation.
[2] Change in event mean concentration (EMC) through the practice.
[3] Note that EMC removal rate is slightly lower in the coastal plain if the wet pond is influenced by groundwater. See **Section 6.2** of this design specification and CSN Technical Bulletin No. 2. (2009).

Sources: CWP and CSN (2008), CWP (2007)

SECTION 3: DESIGN TABLE

The major design goal for Wet Ponds in Virginia is to maximize nutrient removal. To this end, designers may choose to go with the baseline design (Level 1) or choose an enhanced design (Level 2) that maximizes nutrient removal. The basic criteria for the two levels of wet pond design are shown in **Table 14.2** below. At this point, there is no runoff volume reduction credit for wet ponds.

Table 14.2. Level 1 and 2 Wet Pond Design Guidance

Level 1 Design (RR:0 [1]; TP: 50 [5]; TN:30 [5])	Level 2 Design (RR:0 [1]; TP: 75 [5]; TN:40 [5])
Tv = [(1.0)(Rv)(A)/12] – volume reduced by upstream BMP	Tv = [1.5 (Rv) (A) /12] – volume reduced by upstream BMP
Single Pond Cell (with forebay)	Wet ED [2] (24 hr) and/or a Multiple Cell Design [3]
Length/Width ratio OR Flow path = 2:1 or more	Length/Width ratio OR Flow path = 3:1 or more
Length of shortest flow path / overall length [4] = 0.5 or more	Length of shortest flow path/overall length[4] = 0.8 or more
Standard aquatic benches	Wetlands more than 10% of pond area
Turf in pond buffers	Pond landscaping to discourage geese
No Internal Pond Mechanisms	Aeration (preferably bubblers that extend to or near the bottom or floating islands

[1] Runoff volume reduction can be computed for wet ponds designed for water reuse and upland irrigation.
[2] Extended Detention may be provided to meet a maximum of 50% of the Treatment Volume; Refer to Design Specification 15 for ED design
[3] At least three internal cells must be included, including the forebay
[4] In the case of multiple inflows, the flow path is measured from the dominant inflows (that comprise 80% or more of the total pond inflow)
[5] Due to groundwater influence, slightly lower TP and TN removal rates in coastal plain (**Section 7.2**) and CSN Technical Bulletin No. 2. (2009)

Sources: CSN (2009), CWP and CSN (2008), CWP (2007)

SECTION 4: TYPICAL DETAILS

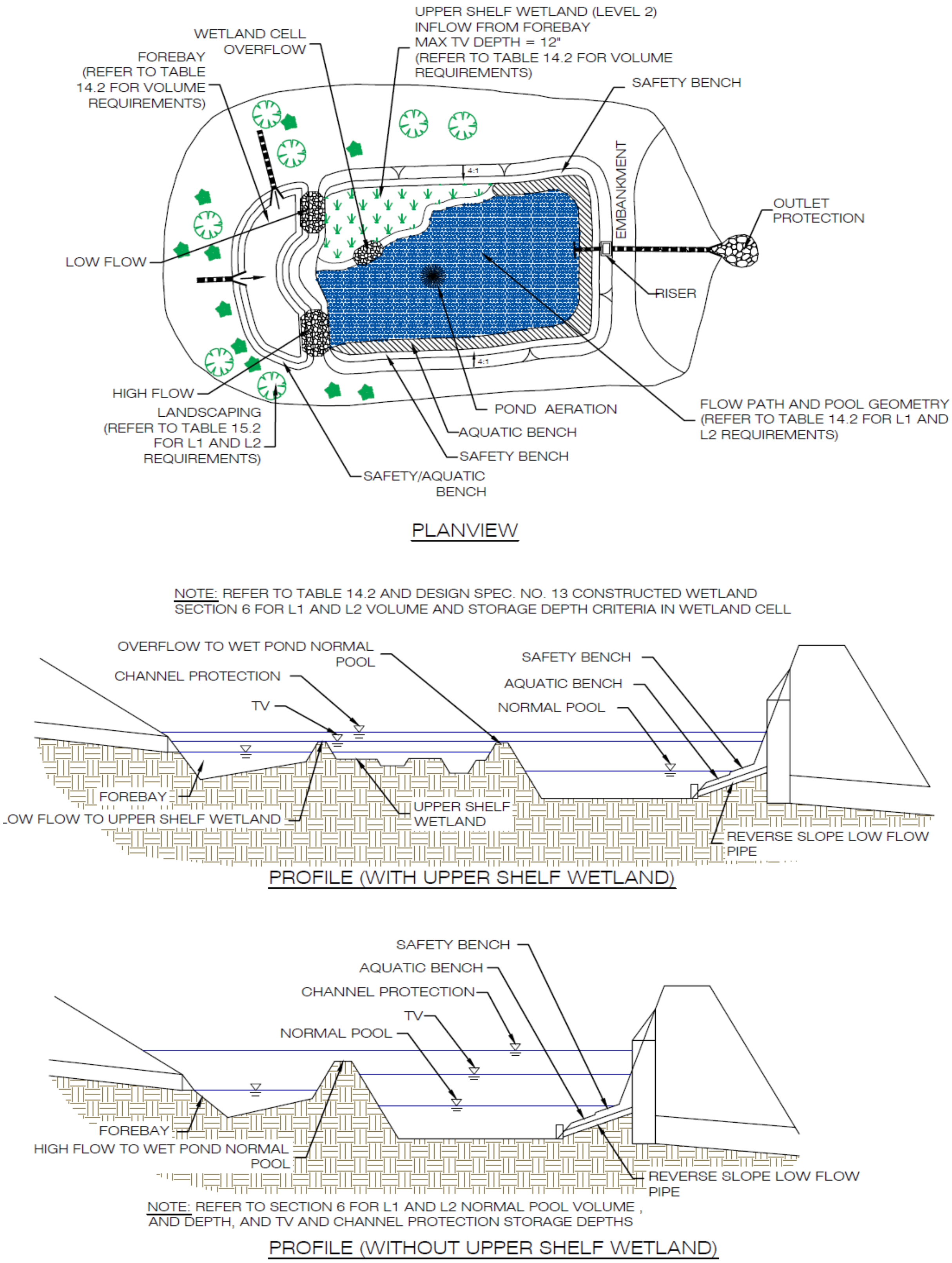


Figure 14.1. Wet Pond Design Schematics

SECTION 5: PHYSICAL FEASIBILITY & DESIGN APPLICATIONS

The following feasibility issues need to be considered when wet ponds are considered as the final BMP of the treatment train.

Space Required. The surface area of a wet pond will normally be at least 1% to 3 % of its contributing drainage area, depending on the pond's depth.

Contributing Drainage Area. A contributing drainage area of 10 to 25 acres is typically recommended for wet ponds to maintain constant water elevations. Wet ponds can still function with drainage areas less than 10 acres, but designers should be aware that these "pocket" ponds will be prone to clogging, experience fluctuating water levels, and generate more nuisance conditions. A water balance should be calculated to assess whether the wet pond will draw down by more than 2 feet after a 30-day summer drought (see equations in **Section 6.2**).

Available Hydraulic Head. The depth of a wet pond is usually determined by the hydraulic head available on the site. The bottom elevation is normally the invert of the existing downstream conveyance system to which the wet pond discharges. Typically, a minimum of 6 to 8 feet of head are needed for a wet pond to function.

Minimum Setbacks. Local ordinances and design criteria should be consulted to determine minimum setbacks to property lines, structures, and wells. As a general rule, wet ponds should be set back at least 20 feet from property lines, 25 feet from building foundations, and 100 feet from septic system fields and private wells.

Depth-to-Water Table. The depth to the groundwater table can be a design concern for wet ponds. If the water table is close to the surface, it may make excavation difficult and expensive. Groundwater inputs can also reduce the pollutant removal rates of wet ponds.

Soils. Highly permeable soils make it difficult to maintain a constant level for the permanent pool in many parts of Virginia. Therefore it is important to directly address fluctuating water levels in the design. Soil infiltration tests need to be conducted at proposed pond sites to determine the need for a pond liner or other method that address water level fluctuation. Underlying soils of Hydrologic Soil Group (HSG) C or D should be adequate to maintain a permanent pool. Most group A soils and some group B soils will require a liner. Geotechnical tests should be conducted to determine the infiltration rates and other subsurface properties of the soils beneath the proposed pond.

Karst. Wet ponds are not recommended in or near karst terrain. An alternative practice or combination of practices should be employed at the site. See CSN Technical Bulletin No.1 (2008) and guidance in Chapter 6 (Appendix 6-A) of the Virginia Stormwater Management Handbook (2010) for guidance on wet pond design in karst terrain.

Trout Streams. The use of wet ponds in watersheds containing trout streams is strongly discouraged, because the discharge can cause stream temperature warming.

Use of or Discharges to Natural Wetlands. It can be tempting to construct a wet pond within an existing natural wetland, but wet ponds cannot be located within jurisdictional waters, including wetlands, without obtaining a section 404 permit from the appropriate state or federal regulatory agency. In addition, the designer should investigate the wetland status of adjacent areas to determine if the discharge from the wet pond will change the hydroperiod of a downstream natural wetland (see Cappiella et al., 2006b, for guidance on minimizing stormwater discharges to existing wetlands).

Perennial streams. Locating wet ponds on perennial streams is also strongly discouraged and will require both a Section 401 and Section 404 permit from the appropriate state or federal regulatory agency.

Design Applications

Wet ponds can be employed in several different design configurations, as illustrated in **Figure 14.1** above:

- Wet Pond with 100% of the permanent pool in a single cell (Level 1 design)
- Wet Extended Detention (ED) and/or multi-cell Wet Pond meeting additional requirements for pond geometry, landscaping, etc. (note that ED may comprise no more than 50% of the total Treatment Volume)
- Pond/Wetland Combination (see Stormwater Design Specification No. 13: Constructed Wetlands)

Wet ponds are widely applicable for most land uses and are best suited for larger drainage areas. It is important to stress that wet ponds are *not* intended to serve as stand-alone stormwater practices, due to their poor runoff volume reduction capability. Designers should always maximize the use of upland runoff reduction practices, such as rooftop disconnections, small-scale infiltration, rainwater harvesting, bioretention, grass channels and dry swales that reduce runoff volume at its source (rather than merely treating runoff at the terminus of the storm drain system). Upland runoff reduction practices can be used to satisfy some or all of the water quality requirements at many sites, which can help to reduce the footprint and volume of wet ponds.

SECTION 6: DESIGN CRITERIA

6.1. Overall Sizing

Wet ponds should be designed to capture and treat the remaining Treatment Volume (T_v) for the water quality design storm and the channel protection volume (if needed) discharged from the upstream runoff reduction practices, using the accepted local or state calculation methods. Designers can use a site-adjusted T_v or CN to reflect the use of upland runoff reduction practices.

To qualify for the higher nutrient reduction rates associated with the Level 2 design, wet ponds must be designed with a Treatment Volume that is 50% greater than the T_v for the Level 1 design [i.e., $1.50(R_v)(A)$]. Research has shown that larger wet ponds with longer residence times enhance algal uptake and nutrient removal rates. Runoff treatment credit may be taken for the following:

Wet Pond – Level 1 design:

- The entire water volume below the normal pool elevation.

Wet ED and/or Multi-Cell Pond – Level 2 design (1.5 T_v):

- The entire water volume below the normal pool elevation (3 internal cells)
- Up to 50% of the T_v may be provided in ED above the permanent pool elevation within one or multiple cells (refer to Stormwater Design Specification No. 15 for ED design).

While most wet ponds have little or no runoff volume reduction capability, they can be designed to promote runoff volume reduction through water reuse (e.g., pumping pond water back into the contributing drainage area for use in seasonal landscape irrigation). While this practice is not common, it has been applied to golf course ponds, and accepted computational methods are available (Wanielista and Yousef, 1993 and McDaniel and Wanielista, 2005). It is recommended that designers be allowed to take credit for annual runoff reduction achieved by pond water reuse, as long as acceptable modeling data is provided for documentation.

6.2 Water Balance Testing

A water balance calculation is recommended to document that sufficient inflows to the pond exist to compensate for combined infiltration and evapo-transpiration losses during a 30-day summer drought without creating unacceptable drawdowns (see **Equation 14.1,** adapted from Hunt et al., 2007). The recommended minimum pool depth to avoid nuisance conditions may vary; however, it is generally recommended that the water balance maintain a minimum 24-inch reservoir.

Equation 14.1. Water Balance Equation for Acceptable Water Depth in a Wet Pond

$$DP > ET + INF + RES - MB$$

Where:

DP	=	Average design depth of the permanent pool (inches)
ET	=	Summer evapo-transpiration rate (inches) (assume 8 inches)
INF	=	Monthly infiltration loss (assume 7.2 @ 0.01 inch/hour)
RES	=	Reservoir of water for a factor of safety (assume 24 inches)
MB	=	Measured baseflow rate to the pond, if any (convert to inches)

Design factors that will alter this equation are the measurements of seasonal base flow and infiltration rate. The use of a liner could eliminate or greatly reduce the influence of infiltration. Similarly, land use changes in the upstream watershed could alter the base flow conditions over time.

Translating the baseflow to inches refers to the depth within the pond. Therefore, the following equation can be used to convert the baseflow, measured in cubic feet per second (ft^3/s), to pond-inches:

$$\text{Pond inches} = ft^3/s * (2.592E6) * (12''/ft) / \text{SA of Pond } (ft^2)$$

Where:

2.592E6	=	Conversion factor: ft^3/s to ft^3/month.
SA	=	suface area of pond in ft^2

6.3. Required Geotechnical Testing

Soil borings should be taken below the proposed embankment, in the vicinity of the proposed outlet area, and in at least two locations within the proposed wet pond treatment area. Soil boring data is needed to (1) determine the physical characteristics of the excavated material, (2) determine its adequacy for use as structural fill or spoil, (3) provide data for structural designs of the outlet works (e.g., bearing capacity and buoyancy), (4) determine compaction/composition needs for the embankment (5) determine the depth to groundwater and bedrock and (6) evaluate potential infiltration losses (and the potential need for a liner).

6.4. Pretreatment Forebay

Sediment forebays are considered to be an integral design feature to maintain the longevity of all wet ponds. A forebay must be located at each major inlet to trap sediment and preserve the capacity of the main treatment cell. Other forms of pre-treatment for sheet flow and concentrated flow for minor inflow points should be designed consistent with pretreatment criteria found in Design Spec No. 9: Bioretention. The following criteria apply to forebay design:

- A major inlet is defined as an individual storm drain inlet pipe or open channel serving at least 10% of the wet pond’s contributing drainage area.
- The forebay consists of a separate cell (in both Level 1 and Level 2 designs), formed by an acceptable barrier (e.g., an earthen berm, concrete weir, gabion baskets, etc.).
- The forebay should be at least 4 feet deep and must be equipped with a variable width aquatic bench for safety purposes. The aquatic bench should be 4 to 6 feet wide at a depth of 1 to 2 feet below the water surface.
- The total volume of all forebays should be at least 15% of the total Treatment Volume (inclusive). The relative size of individual forebays should be proportional to the percentage of the total inflow to the wet pond. Similarly, any outlet protection associated with the end section or end wall should be designed according to state or local design standards.
- The bottom of the forebay may be hardened (e.g., with concrete, asphalt, or grouted riprap) to make sediment removal easier.
- The forebay should be equipped with a metered rod in the center of the pool (as measured lengthwise along the low flow water travel path) for long-term monitoring of sediment accumulation.

6.5. Conveyance and Overflow

Internal Slope. The longitudinal slope through the pond should be at least 0.5% to 1% to promote positive flow through the pond practice.

Primary Spillway. The spillway shall be designed with acceptable anti-flotation, anti-vortex and trash rack devices. The spillway must generally be accessible from dry land. Refer to **Appendix B: Principal Spillways** of the *Introduction to the New Virginia Stormwater Design Specifications*, as posted on the Virginia Stormwater BMP Clearinghouse web site, at the following web site:

http://www.vwrrc.vt.edu/swc/NonProprietaryBMPs.html

Non-Clogging Low Flow Orifice. A low flow orifice must be provided that is adequately protected from clogging by either an acceptable external trash rack or by internal orifice protection that may allow for smaller diameters. Orifices less than 3 inches in diameter may require extra attention during design, to minimize the potential for clogging.

- One option is a submerged reverse-slope pipe that extends downward from the riser to an inflow point 1 foot below the normal pool elevation.
- Alternative methods must employ a broad crested rectangular V-notch (or proportional) weir, protected by a half-round CMP that extends at least 12 inches below the normal pool elevation.

Emergency Spillway. Wet Ponds must be constructed with overflow capacity to pass the 100-year design storm event through either the Primary Spillway or a vegetated or armored Emergency Spillway. Refer to **Appendix C: Emergency Spillways** of the *Introduction to the New Virginia Stormwater Design Specifications*, as posted on the Virginia Stormwater BMP Clearinghouse web site (the URL is on the previous page).

Pond Drain. Except for flat areas of the coastal plain, each wet pond should have a drain pipe that can completely or partially drain the permanent pool. In cases where a low level drain is not feasible (such as in an excavated pond), a pump wet well should be provided to accommodate a temporary pump intake when needed to drain the pond.

- The drain pipe should have an upturned elbow or protected intake within the pond, to prevent sediment deposition, and a diameter capable of draining the pond within 24 hours.
- The pond drain must be equipped with an adjustable valve located within the riser, where it will not be normally inundated and can be operated in a safe manner.

Adequate Outfall Protection. The design must specify an outfall that will be stable for the 10-year design storm event. The channel immediately below the pond outfall must be modified to prevent erosion and conform to natural dimensions in the shortest possible distance. This is typically done by placing appropriately sized riprap over filter fabric, which can reduce flow velocities from the principal spillway to non-erosive levels (3.5 to 5.0 fps). Flared pipe sections, which discharge at or near the stream invert or into a step pool arrangement, should be used at the spillway outlet.

Inlet Protection. Inlet areas should be stabilized to ensure that non-erosive conditions exist during storm events up to the overbank flood event (i.e., the 10-year storm event). Inlet pipe inverts should generally be located at or slightly below the permanent pool elevation.

Dam Safety Permits. Wet ponds with high embankments or large drainage areas and impoundments may may be regulated under the Virginia Dam Safety Act (§ 10.1-606.1 et seq., Code of Virginia) and the Virginia Dam Safety Regulations (4 VAC 50-20 et seq.). Refer to Design Specification Appendix A: Earthen Embankments for additional information.

6.6. Internal Design Geometry

Side Slopes. Side slopes for the wet pond should generally have a gradient of 4H:1V to 5H:1V. The mild slopes promote better establishment and growth of vegetation and provide for easier maintenance and a more natural appearance.

Long Flow Path. Wet pond designs should have an irregular shape and a long flow path from inlet to outlet, to increase water residence time and pond performance. In terms of flow path geometry, there are two design considerations: (1) the overall flow path through the pond, and (2) the length of the shortest flow path (Hirschman et al., 2009).

- The overall flow path can be represented as the length-to-width ratio *OR* the flow path ratio (see the *Introduction to the New Virginia Stormwater Design Specifications*, as posted on the Virginia Stormwater BMP Clearinghouse web site for diagrams and equations). These ratios must be at least 2L:1W for Level 1 designs and 3L:1W for Level 2 designs. Internal berms, baffles, or vegetated pennisulas can be used to extend flow paths and/or create multiple pond cells.
- The shortest flow path represents the distance from the closest inlet to the outlet (see the *Introduction to the New Virginia Stormwater Design Specifications*, as posted on the Virginia Stormwater BMP Clearinghouse web site). The ratio of the shortest flow to the overall length must be at least 0.5 for Level 1 designs and 0.8 for Level 2 designs. In some cases – due to site geometry, storm sewer infrastructure, or other factors – some inlets may not be able to meet these ratios. However, the drainage area served by these “closer” inlets should constitute no more than 20% of the total contributing drainage area.

Treatment Volume Storage. The total T_v storage may be provided by a combination of the permanent pool, a shallow marsh and/or extended detention storage. The permanent pool storage can be provided in multiple cells. Performance is enhanced when multiple treatment pathways are provided by using multiple cells, longer flow paths, high surface area-to-volume ratios, and/or redundant treatment methods (e.g., a combinations of the permanent pool, ED, and a shallow marsh). A berm or simple weir should be used instead of pipes to separate multiple pond cells.

Maximum Extended Detention Levels. The maximum extended detention volume associated with the T_v may not extend more than 12 inches above the wetland cell permanent pool (at least 10% of the Level 2 surface area) at its maximum water surface elevation. The maximum ED and channel protection detention levels can be up to 5 feet above the wet pond permanent pool.

Stormwater Pond Benches. The perimeter of all pool areas greater than 4 feet in depth must be surrounded by two benches, as follows:

- A ***Safety Bench*** is a flat bench located just outside of the perimeter of the permanent pool to allow for maintenance access and reduce safety risks. Except when the stormwater pond side slopes are 5H:1V or flatter, provide a safety bench that generally extends 8 to 15 feet outward from the normal water edge to the toe of the stormwater pond side slope The maximum slope of the safety bench is 5%.
- An ***Aquatic Bench*** is a shallow area just inside the perimeter of the normal pool that promotes growth of aquatic and wetland plants. The bench also serves as a safety feature, reduces shoreline erosion, and conceals floatable trash. Incorporate an aquatic bench that generally extends up to 10 feet inward from the normal shoreline, has an irregular configuration, and extends a maximum depth of 18 inches below the normal pool water surface elevation.

Safety Features.

- The principal spillway opening must be designed and constructed to prevent access by small children.
- End walls above pipe outfalls greater than 48 inches in diameter must be fenced to prevent a hazard.
- An emergency spillway and associated freeboard must be provided in accordance with applicable local or state dam safety requirements. The emergency spillway must be located so that downstream structures will not be impacted by spillway discharges.
- Both the safety bench and the aquatic bench should be landscaped with vegetation that hinders or prevents access to the pool.
- Warning signs prohibiting swimming should be posted.
- Fencing of the perimeter of wet ponds is discouraged. The preferred method to reduce risk is to manage the contours of the stormwater pond to eliminate drop-offs or other safety hazards. Fencing is required at or above the maximum water surface elevation in the rare situations when the pond slope is a vertical wall.

6.7. Landscaping and Planting Plan

A landscaping plan must be provided that indicates the methods used to establish and maintain vegetative coverage in the pond and its buffer. Minimum elements of a plan include the following:

- Delineation of pondscaping zones within both the pond and buffer
- Selection of corresponding plant species
- The planting plan

- The sequence for preparing the wetland benches (including soil amendments, if needed)
- Sources of native plant material
- The landscaping plan should provide elements that promote diverse wildlife and waterfowl use within the stormwater wetland and buffers.
- Woody vegetation may not be planted or allowed to grow within 15 feet of the toe of the embankment nor within 25 feet from the principal spillway structure.
- A vegetated buffer should be provided that extends at least 25 feet outward from the maximum water surface elevation of the wet pond. Permanent structures (e.g., buildings) should not be constructed within the buffer area. Existing trees should be preserved in the buffer area during construction.
- The soils in the stormwater buffer area are often severely compacted during the construction process, to ensure stability. The density of these compacted soils can be so great that it effectively prevents root penetration and, therefore, may lead to premature mortality or loss of vigor. As a rule of thumb, planting holes should be three times deeper and wider than the diameter of the root ball for ball-and-burlap stock, and five times deeper and wider for container-grown stock.
- Avoid species that require full shade, or are prone to wind damage. Extra mulching around the base of trees and shrubs is strongly recommended as a means of conserving moisture and suppressing weeds.

For more guidance on planting trees and shrubs in wet pond buffers, consult the following:

- Cappiella et al (2006)
- Riparian Buffer Modification & Mitigation Guidance Manual, available online at: http://www.deq.virginia.gov/Programs/Water/ChesapeakeBay/ChesapeakeBayPreservationAct/LocalProgramTechnicalAssistance/ChesapeakeBayPreservationAreas.aspx
- Appendix E: Landscaping of the Introduction to the New Virginia Stormwater Design Specifications , as posted on the Virginia Stormwater BMP Clearinghouse web site.

6.8. Maintenance Reduction Features

The following wet pond maintenance issues can be addressed during the design, in order to make on-going maintenance easier:

- ***Maintenance Access.*** Good access is needed so crews can remove sediments, make repairs and preserve pond treatment capacity).
    - Adequate maintenance access must extend to the forebay, safety bench, riser, and outlet structure and must have sufficient area to allow vehicles to turn around.
    - The riser should be located within the embankment for maintenance access, safety and aesthetics. Access to the riser should be provided by lockable manhole covers and manhole steps within easy reach of valves and other controls.
    - Access roads must (1) be constructed of load-bearing materials or be built to withstand the expected frequency of use, (2) have a minimum width of 12 feet, and (3) have a profile grade that does not exceed15%. Steeper grades are allowable if appropriate stabilization techniques are used, such as a gravel road.

  - A maintenance right-of-way or easement must extend to the stormwater pond from a public or private road.
- ***Liners.*** When a stormwater pond is located over highly permeable soils or fractured bedrock, a liner may be needed to sustain a permanent pool of water. If geotechnical tests confirm the need for a liner, acceptable options include the following: (1) a clay liner following the specifications outlined in **Table 14.4** below; (2) a 30 mil poly-liner; (3) bentonite; (4) use of chemical additives; or (5) an engineering design, as approved on a case-by-case basis by the local review authority. A clay liner should have a minimum thickness of 12 inches with an additional 12 inch layer of compacted soil above it, and it must meet the specifications outlined in **Table 14.4**. Other synthetic liners can be used if the designer can supply supporting documentation that the material will achieve the required performance.

Table 14.4. Clay Liner Specifications

Property	Test Method	Unit	Specification
Permeability	ASTM D-2434	Cm/sec	1×10^{-6}
Plasticity Index of Clay	ASTM D-423/424	%	Not less than 15
Liquid Limit of Clay	ASTM D-2216	%	Not less than 30
Clay Particles Passing	ASTM D-422	%	Not less than 30
Clay Compaction	ASTM D-2216	%	95% of standard proctor density

Source: Virginia Stormwater Management Handbook (1999)

6.9. Wet Pond Material Specifications

Wet ponds are generally constructed with materials obtained on-site, except for the plant materials, inflow and outflow devices (e.g., piping and riser materials), possibly stone for inlet and outlet stabilization, and filter fabric for lining banks or berms.

The basic material specifications for earthen embankments, principal spillways, vegetated emergency spillways and sediment forebays shall be as specified in **Appendices A through D** of the *Introduction to the New Virginia Stormwater Design Specifications*, as posted on the Virginia Stormwater BMP Clearinghouse web site, at the following URL:

http://www.vwrrc.vt.edu/swc/NonProprietaryBMPs.html

When reinforced concrete pipe is used for the principal spillway to increase its longevity, "O"-ring gaskets (ASTM C-361) should be used to create watertight joints, and they should be inspected during installation.

SECTION 7: REGIONAL & SPECIAL CASE DESIGN ADAPTATIONS

7.1. Karst Terrain

Karst regions are found in much of the Ridge and Valley province of Virginia. The presence of karst complicates both land development in general and stormwater design in particular. Designers should always conduct geotechnical investigations in karst terrain to assess this risk ~~in~~ during the project planning stage. Because of the risk of sinkhole formation, groundwater contamination, and frequent facility failures, use of wet ponds is highly restricted in karst regions (see CSN Technical Bulletin No. 1, 2008, and Appendix 6-C of Chapter 6 of the Virginia Stormwater Management Handbook, 2010). At a minimum, designers must specify the following:

- A minimum of 6 feet of unconsolidated soil material exists between the bottom of the basin and the top of the karst layer.
- Maximum temporary or permanent water elevations within the basin does not exceed 6 feet.
- Annual maintenance inspections must be conducted to detect sinkhole formation. Sinkholes that develop should be reported immediately after they have been observed, and should be repaired, abandoned, adapted or observed over time following the guidance prescribed by the appropriate local or state groundwater protection authority (see **Section 9.3**)
- A liner is installed that meets the requirements outlined in **Table 14.5**.

Table 14.5. Required Groundwater Protection Liners for Ponds in Karst Terrain (WVDEP, 2006 and Virginia Stormwater Management Handbook, 1999)

Situation	Criteria
Pond *not* excavated to bedrock	24 inches of soil with a maximum hydraulic conductivity of 1 x 10^{-5} cm/sec.
Pond excavated to or near bedrock	24 inches of clay[1] with a maximum hydraulic conductivity of 1 x 10^{-6} cm/sec.
Pond excavated to bedrock within a wellhead protection area, in a recharge area for a domestic well or spring, or in a known faulted or folded area	Synthetic liner with a minimum thickness of 60 mil.
[1] Clay properties as follows: Plasticity Index of Clay = Not less than 15% (ASTM D-423/424) Liquid Limit of Clay = Not less than 30% (ASTM D-2216) Clay Particles Passing = Not less than 30% (ASTM D-422) Clay Compaction = 95% of standard proctor density (ASTM D-2216)	

Source: WVDEP (2006) and Virginia Stormwater Management Handbook (1999)

7.2. Coastal Plain

The flat terrain, low hydraulic head and high water table of many coastal plain sites can constrain the application of wet ponds. Excavating ponds below the water table creates what are known as dugout ponds, where the treatment volume is displaced by groundwater, reducing the pond's mixing and treatment efficiency and creating nuisance conditions. In addition, pond drains may not be practicable in extremely flat terrain.

Wet ponds are considered an *"acceptable"* stormwater practice for use in the coastal plain where the water table is within four feet of the land surface. However, constructed wetlands are a preferred alternative in such settings, if space is available. The following are important design considerations pertaining to wet ponds located in coastal plain settings:

- ***Adjustments to the Nutrient Removal Credit***. Numerous research findings indicate that the criteria in this design specification for wet ponds *cannot* achieve the same level of nutrient removal that can be achieved in the rest of Virginia (based on current design, detention times, the influence of groundwater and other factors). Therefore, slightly lower nutrient removal rates are assigned to coastal plain wet ponds, to reflect real world performance data for phosphorus and nitrogen removal. Specifically, Level 1 and 2 total removal rates for TP are now proposed to be 45% and 65% respectively, and Level 1 and 2 TN removal rates are reduced to 20% and 30%, respectively. These slightly lower removal rates are supported by pond research and the detention time relationships (see CSN Technical Bulletin No. 2, 2009).

- ***Pocket Ponds.*** Another issue relates to wet ponds with a small contributing drainage area that are solely supplied by runoff and groundwater, and often have fluctuating water levels that create nuisance conditions. There is virtually no research data on these "pocket ponds" that are frequently installed on small commercial sites. Rather than mandating an arbitrary minimum drainage area, it is recommended instead that these pocket ponds must meet the minimum design geometry requirements for all ponds (i.e., a sediment forebay cell, aquatic benches, maximum side-slopes no steeper than 5H: 1V, and a length-to-width ratio of 2:1 for Level 1 designs or 3:1 for Level 2 designs). Designers should strictly adhere to the same design requirements that apply to other wet ponds. This should greatly reduce the number of small nuisance ponds with inadequate designs and insufficient functions (i.e., by reducing or eliminating essential pond design elements), that are forced into sites that are too small.

7.3. Steep Terrain

The use of wet ponds is highly constrained at development sites with steep terrain. Some adjustment can be made by terracing pond cells in a linear manner, using a 1 to 2 foot armored elevation drop between individual cells. Terracing may work well on longitudinal slopes with gradients up to approximately 10%.

7.4. Cold Climate and Winter Performance

Pond performance decreases when snowmelt runoff delivers high pollutant loads. Ponds can also freeze in the winter, which allows runoff to flow over the ice layer and exit without treatment. Inlet and outlet structures close to the surface may also freeze, further diminishing pond performance. Salt loadings are higher in cold climates due to winter road maintenance. The following design adjustments are recommended for wet ponds installed in higher elevations and colder climates:

- Treat larger runoff volumes in the spring by adopting seasonal operation of the permanent pool (see MSSC, 2005).
- Plant salt-tolerant vegetation in pond benches.
- Do not submerge inlet pipes, and provide a minimum 1% pipe slope to discourage ice formation.
- Locate low flow orifices so they withdraw at least 6 inches below the typical ice layer.
- Place trash racks at a shallow angle to prevent ice formation.
- Oversize riser and weir structures to avoid ice formation and pipe freezing.
- If winter road sanding is prevalent in the contributing drainage area, increase the forebay size to accommodate additional sediment loading.

7.5. Linear Highway Sites

Wet ponds are poorly suited to treat runoff within open channels located in the highway right of way, unless storage is available in a cloverleaf interchange or in an expanded right-of-way. Guidance for pond construction in these areas is provided in Profile Sheet SR-5 in Schueler et al (2007).

SECTION 8: CONSTRUCTION

8.1. Construction Sequence

The following is a typical construction sequence to properly install a wet pond. The steps may be modified to reflect different wet pond designs, site conditions, and the size, complexity and configuration of the proposed facility.

Step 1: Use of Wet Pond as an E&S Control. A wet pond may serve as a sediment basin during project construction. If this is done, the volume should be based on the more stringent sizing rule (erosion and sediment control requirement vs. water quality treatment requirement). Installation of the permanent riser should be initiated during the construction phase, and design elevations should be set with final cleanout of the sediment basin and conversion to the post-construction wet pond in mind. The bottom elevation of the wet pond should be lower than the bottom elevation of the temporary sediment basin. Appropriate procedures should be implemented to prevent discharge of turbid waters when the basin is being converted into a wet pond.

Step 2: Stabilize the Drainage Area. Wet ponds should only be constructed after the contributing drainage area to the pond is completely stabilized. If the proposed pond site will be used as a sediment trap or basin during the construction phase, the construction notes should clearly indicate that the facility will be de-watered, dredged and re-graded to design dimensions after the original site construction is complete.

Step 3: Assemble Construction Materials on-site, make sure they meet design specifications, and prepare any staging areas.

Step 4: Clear and Strip the project area to the desired sub-grade.

Step 5: Install E&S Controls prior to construction, including temporary de-watering devices and stormwater diversion practices. All areas surrounding the pond that are graded or denuded during construction must be planted with turf grass, native plantings, or other approved methods of soil stabilization.

Step 6: Excavate the Core Trench and Install the Spillway Pipe.

Step 7: Install the Riser or Outflow Structure, and ensure the top invert of the overflow weir is constructed level at the design elevation.

Step 8: Construct the Embankment and Any Internal Berms in 8- to 12-inch lifts, compact the lifts with appropriate equipment.

Step 9: Excavate/Grade until the appropriate elevation and desired contours are achieved for the bottom and side slopes of the pond.

Step 10: Construct the Emergency Spillway in cut or structurally stabilized soils.

Step 11: Install Outlet Pipes, including downstream rip-rap apron protection.

Step 12: Stabilize Exposed Soils with temporary seed mixtures appropriate for the pond buffer. All areas above the normal pool elevation should be permanently stabilized by hydroseeding or seeding over straw.

Step 13: Plant the Pond Buffer Area, following the pondscaping plan (see **Section 8.5** below).

8.2. Construction Inspection

Multiple inspections are critical to ensure that stormwater ponds are properly constructed. Inspections are recommended during the following stages of construction:

- Pre-construction meeting
- Initial site preparation (including installation of E&S controls)
- Excavation/Grading (interim and final elevations)
- Installation of the embankment, the riser/primary spillway, and the outlet structure
- Implementation of the pondscaping plan and vegetative stabilization
- Final inspection (develop a punchlist for facility acceptance)

A construction phase inspection checklist for Wet Ponds can be accessed in at the CWP website at:

http://www.cwp.org/Resource_Library/Controlling_Runoff_and_Discharges/sm.htm
(scroll to Tool6: Plan Review, BMP Construction, and Maintenance Checklists)

For larger wet ponds, use the expanded construction inspection form provided in Appendix B of CWP (2004).

To facilitate maintenance, contractors should measure the actual constructed pond depth at three areas within the permanent pool (forebay, mid-pond and at the riser), and they should mark and geo-reference them on an as-built drawing. This simple data set will enable maintenance inspectors to determine pond sediment deposition rates in order to schedule sediment cleanouts.

SECTION 9: MAINTENANCE

9.1. Maintenance Agreements

Section 4 VAC 50-60-124 of the regulations specifies the circumstances under which a maintenance agreement must be executed between the owner and the local program. This section sets forth inspection requirements, compliance procedures if maintenance is neglected, notification of the local program upon transfer of ownership, and right-of-entry for local program personnel. Access to wet ponds should be covered by a drainage easement to allow inspection and maintenance.

It is also recommended that the maintenance agreement include a list of qualified contractors that can perform inspection or maintenance services, as well as contact information for owners to get local or state assistance to solve common nuisance problems, such as mosquito control, geese, invasive plants, vegetative management, and beaver removal. The CWP *Pond and Wetland Maintenance Guidebook* (2004) provides some excellent templates of how to respond to these problems.

9.2. First Year Maintenance Operations

Successful establishment of wet ponds requires that the following tasks be undertaken during the first year following construction.

Initial inspections**.** For the first six months following construction, the site should be inspected at least twice after storm events that exceed a 1/2-inch of rainfall.

Planting of Aquatic Benches. The aquatic benches should be planted with emergent wetland species, following the planting recommendations contained in Stormwater Design Specification No. 13 (Constructed Wetlands).

Spot Reseeding. Inspectors should look for bare or eroding areas in the contributing drainage area or around the pond buffer, and make sure they are immediately stabilized with grass cover.

Watering. Trees planted in the pond buffer need to be watered during the first growing season. In general, consider watering every 3 days for first month, and then weekly during the remainder of the first growing season (April - October), depending on rainfall.

9.3. Inspections and Ongoing Maintenance Tasks

Maintenance of a wet pond is driven by annual inspections that evaluate the condition and performance of the pond, including the following:

- Measure sediment accumulation levels in the forebay.
- Monitor the growth of wetland plants, trees and shrubs planted. Record the species and their approximate coverage, and note the presence of any invasive plant species.

- Inspect the condition of stormwater inlets to the pond for material damage, erosion or undercutting.
- Inspect the banks of upstream and downstream channels for evidence of sloughing, animal burrows, boggy areas, woody growth, or gully erosion that may undermine embankment integrity.
- Inspect the pond outfall channel for erosion, undercutting, rip-rap displacement, woody growth, etc.
- Inspect the condition of the principal spillway and riser for evidence of spalling, joint failure, leakage, corrosion, etc.
- Inspect the condition of all trash racks, reverse-sloped pipes, or flashboard risers for evidence of clogging, leakage, debris accumulation, etc.
- Inspect maintenance access to ensure it is free of woody vegetation, and check to see whether valves, manholes and locks can be opened and operated.
- Inspect internal and external side slopes of the pond for evidence of sparse vegetative cover, erosion, or slumping, and make needed repairs immediately.

Based on inspection results, specific maintenance tasks will be triggered. Example maintenance inspection checklists for Wet Ponds can be accessed in Appendix C of Chapter 9 of the *Virginia Stormwater Management Handbook* (2010) or at the CWP website at:

http://www.cwp.org/Resource_Library/Controlling_Runoff_and_Discharges/sm.htm
(scroll to Tool6: Plan Review, BMP Construction, and Maintenance Checklists)

For a more detailed maintenance inspection checklist, see Appendix B in CWP *Stormwater Pond and Wetland Maintenance Guidebook* (2004).

Maintenance is needed so stormwater ponds continue to operate as designed on a long-term basis. Wet ponds normally have fewer routine maintenance requirements than other stormwater control measures. Stormwater pond maintenance activities vary regarding the level of effort and expertise required to perform them. Routine stormwater pond maintenance, such as mowing and removing debris and trash, is needed several times each year (See **Table 14.6**). More significant maintenance (e.g., removing accumulated sediment) is needed less frequently but requires more skilled labor and special equipment. Inspection and repair of critical structural features (e.g., embankments and risers) needs to be performed by a qualified professional (e.g., a structural engineer) who has experience in the construction, inspection, and repair of these features.

The maintenance plan should clearly outline how vegetation in the pond and its buffer will be managed or harvested in the future. Periodic mowing of the stormwater buffer is only required along maintenance rights-of-way and the embankment. The remaining buffer can be managed as a meadow (mowing every other year) or forest. The maintenance plan should schedule a shoreline cleanup at least once a year to remove trash and floatables.

Table 14.6. Typical Wet Pond Maintenance Tasks and Frequency

Maintenance Items	Frequency
• Mowing – twice a year • Remove debris and blockages • Repair undercut, eroded, and bare soil areas	Quarterly or after major storms (>1 inch of rainfall)
• Mowing	Twice a year
• Shoreline cleanup to remove trash, debris and floatables • A full maintenance inspection • Open up the riser to access and test the valves • Repair broken mechanical components, if needed	Annually
• Pond buffer and aquatic bench reinforcement plantings	One time –during the second year following construction
• Forebay Sediment Removal	Every 5 to 7 years
• Repair pipes, the riser and spillway, as needed	From 5 to 25 years

9.4. Sediment Removal

Frequent sediment removal from the forebay is essential to maintain the function and performance of a wet pond. Maintenance plans should schedule cleanouts approximately every 5 to 7 years, or when inspections indicate that 50% of forebay sediment storage capacity has been filled. The designer should also check to see whether removed sediments can be spoiled on-site or must be hauled away. Sediments excavated from wet ponds are not usually considered toxic or hazardous. They can be safely disposed of by either land application or land filling. Sediment testing may be needed prior to sediment disposal if the retrofit serves a hotspot land use.

SECTION 10: COMMUNITY & ENVIRONMENTAL CONCERNS

Wet ponds can generate the following community and environmental concerns that need to be addressed during design.

Aesthetic Issues. Many residents feel that wet ponds are an attractive landscape feature, promote a greater sense of community and are an attractive habitat for fish and wildlife. Designers should note that these benefits are often diminished where wet ponds are under-sized or have small contributing drainage areas.

Existing Wetlands. A wet pond should never be constructed within an existing *natural* wetland. Discharges from a wet pond into an existing natural wetland should be minimized to prevent pollution damage and changes to its hydroperiod.

Existing Forests. Construction of a wet pond may involve extensive clearing of existing forest cover. Designers can expect a great deal of neighborhood opposition if they do not make a concerted effort to save mature trees during pond design and construction.

Stream Warming Risk. Wet ponds can warm streams by 2 to 10 degrees Fahrenheit, although this may not be a major problem for degraded urban streams. To minimize stream warming, wet ponds should be shaded and should provide shorter extended detention times (e.g., 12 hours vs. 24 hours).

Safety Risk. Pond safety is an important community concern, since both young children and adults have perished by drowning in wet ponds through a variety of accidents, including falling through thin ice cover. Gentle side slopes and safety benches should be provided to avoid potentially dangerous drop-offs, especially where wet ponds are located near residential areas.

Mosquito Risk. Mosquitoes are not a major problem for larger wet ponds (Santana *et al*., 1994; Ladd and Frankenburg, 2003, Hunt et al, 2005). However, fluctuating water levels in smaller or under-sized wet ponds could pose some risk for mosquito breeding. Mosquito problems can be minimized through simple design features and maintenance operations described in MSSC (2005).

Geese and Waterfowl. Wet ponds with extensive turf and shallow shorelines can attract nuisance populations of resident geese and other waterfowl, whose droppings add to the nutrient and bacteria loads, thus reducing the removal efficiency for those pollutants. Several design and landscaping features can make wet ponds much less attractive to geese (see Schueler, 1992).

Harmful Algal Blooms. Designers are cautioned that recent research on wet ponds in the coastal plain has shown that some ponds can be hotspots or incubators for algae that generate harmful algal blooms (HABs). The type of HAB may include cyanobacteria, raphidophytes, or dinoflagellates, and the severity appears to be related to environmental conditions and high nutrient inputs. Given the known negative effects of HABs on the health of shellfish, fish, wildlife and humans, this finding is a cause for concern for coastal stormwater managers. At this time, it is not possible to develop design guidelines to avoid HAB problems in coastal wet ponds. A summary of recent pond research on this emerging issue can be found in Appendix A of Technical Bulletin No. 2, Stormwater Design in the Coastal Plain of the Chesapeake Bay Watershed(CSN,2009).

SECTION 11: REFERENCES

Cappiella, K., T. Schueler and T. Wright. 2006. *Urban Watershed Forestry Manual: Part 2: Conserving and Planting Trees at Development Sites*. USDA Forest Service. Center for Watershed Protection. Ellicot City, MD

Center for Watershed Protection (CWP). 2004. *Pond and Wetland Maintenance Guidebook*. Ellicott City, MD.

CWP. 2007. *National Pollutant Removal Performance Database Version 3.0*. Center for Watershed Protection, Ellicott City, MD.

Chesapeake Stormwater Network (CSN). 2008. *Technical Bulletin 1: Stormwater Design Guidelines for Karst Terrain in the Chesapeake Bay Wateshed*. Version 1.0. Baltimore, MD.

CSN. 2009. *Technical Bulletin 2: Stormwater Design Guidelines in the Coastal Plain of the Chesapeake Bay Watershed*. Version 2.0. Baltimore, MD.

Galli, J. 1990b. *Thermal Impacts Associated with Urbanization and Stormwater Best Management Practices*. Metropolitan Washington Council of Governments. Washington, D.C.

Hirschman, D., L. Woodworth and S. Drescher. 2009. *Technical Report: Stormwater BMPs in Virginia's James River Basin – An Assessment of Field Conditions and Programs*. Center for Watershed Protection. Ellicott City, MD.

Hirschman, D. and J. Kosco. 2008. *Managing Stormwater in Your Community: A Guide for Building an Effective Post-Construction Program*. EPA Publication 833-R-08-001. Tetra-tech, Inc. and the Center for Watershed Protection. Ellicott City, MD.

Hunt, W. and W. Lord. 2006. "Maintenance of Stormwater Wetlands and Wet Ponds." *Urban Waterways*. North Carolina State University and North Carolina Cooperative Extension. Raliegh, NC.

Hunt, W., C. Apperson, and W. Lord. 2005. "Mosquito Control for Stormwater Facilities." *Urban Waterways*. North Carolina State University and North Carolina Cooperative Extension. Raliegh, NC.

Hunt, W., M. Burchell, J. Wright and K. Bass. 2007. "Stormwater Wetland Design Update: Zones, Vegetation, Soil and Outlet Guidance." *Urban Waterways*. North Carolina State Cooperative Extension Service. Raliegh, NC.

Ladd, B and J. Frankenburg. 2003. Management of Ponds, Wetlands and Other Water Resorvoirs. Purdue Extension. WQ-41-W.

Maryland Department of Environment (MDE). 2000. *Maryland Stormwater Design Manual*. Baltimore, MD. Available online at: http://www.mde.state.md.us/Programs/WaterPrograms/SedimentandStormwater/stormwater_design/index.asp

McDaniel, J. and M. Wanielista. 2005. *Stormwater Intelligent Controller System. Final Report to the Florida DEP*. University of Central Florida Stormwater Management Academy. http://www.floridadep.org/water/nonpoint/docs/nonpoint/Stormwater_I_ControllerFinalReport.pdf

Minnesota Stormwater Steering Committee (MSSC). 2005. *Minnesota Stormwater Manual*. Emmons & Oliver Resources, Inc. Minnesota Pollution Control Agency. St. Paul, MN.

Santana, F., J. Wood, R. Parsons, and S. Chamberlain. 1994. *Control of Mosquito Breeding in Permitted Stormwater Systems*. Southwest Florida Water Management District. Brooksville, FL.

Schueler, T, 1992. *Design of Stormwater Wetland Systems*. Metropolitan Washington Council of Governments. Washington, DC.

Schueler, T., D. Hirschman, M. Novotney and J. Zielinski. 2007. *Urban Stormwater Retrofit Practices*. Manual 3 in the Urban Subwatershed Restoration Manual Series. Center for Watershed Protection. Ellicott City, MD.

Schueler, T. 2008. Technical Support for the Baywide Runoff Reduction Method. Chesapeake Stormwater Network. Baltimore, MD. www.chesapeakestormwater.net

Virginia Stormwater Management Handbook. 1999. *Volumes 1 and 2*. Richmond, VA.

Wanielista, M. and Y. Yousef. 1993. "Design and Analysis of Irrigation Ponds Using Urban Stormwater Runoff." *ASCE Engineering Hydrology*. 724-728. Also see Article 82 in the CWP *Practice of Watershed Protection.*

VIRGINIA DEQ STORMWATER
DESIGN SPECIFICATION No. 15

EXTENDED DETENTION (ED) POND

VERSION 1.9
March 1, 2011

SECTION 1: DESCRIPTION

An Extended Detention (ED) Pond relies on 12 to 24 hour detention of stormwater runoff after each rain event. An under-sized outlet structure restricts stormwater flow so it backs up and is stored within the basin. The temporary ponding enables particulate pollutants to settle out and reduces the maximum peak discharge to the downstream channel, thereby reducing the effective shear stress on banks of the receiving stream. ED differs from stormwater detention, since it is designed to achieve a minimum drawdown time, rather than a maximum peak rate of flow (which is commonly used to design for peak discharge or flood control purposes and often detains flows for just a few minutes or hours). However, detention used for channel protection, may result in extended drawdown times. Therefore, designers are encouraged to evaluate the detention drawdown as compared to the ED requirements in order to meet both criteria. ED ponds rely on gravitational settling as their primary pollutant removal mechanism. Consequently, they generally provide fair-to-good removal for particulate pollutants, but low or negligible removal for soluble pollutants, such as nitrate and soluble phosphorus. The use of ED alone generally results in the lowest overall pollutant removal rate of any single stormwater treatment option. As a result, ED is normally combined with wet ponds (Design Specification No 14) or constructed wetlands (Design Specification No 15) to maximize pollutant removal rates.
Designers should note that an ED pond is the final element in the roof to stream runoff reduction sequence, so one **should be considered *only* if there is remaining Treatment Volume or Channel Protection Volume to manage after all other upland runoff reduction practices have been considered and properly credited.** Designers may need to submit documentation to the local plan review authority showing that all other runoff reduction opportunities have been

exhausted and were found to be insufficient, leaving additional water quality or Channel Protection Volume to manage.

SECTION 2: PERFORMANCE

Table 15.1. Summary of Stormwater Functions Provided by ED Ponds

Stormwater Function	Level 1 Design	Level 2 Design
Annual Runoff Volume Reduction (RR)	0%	15%
Total Phosphorus (TP) EMC Reduction[1] by BMP Treatment Process	15%	15%
Total Phosphorus (TP) Mass Load Removal	15%	31%
Total Nitrogen (TN) EMC Reduction[1] by BMP Treatment Process	10%	10%
Total Nitrogen (TN) Mass Load Removal	10%	24%
Channel Protection	Yes; storage volume can be provided to accommodate the full Channel Protection Volume (CP_V)	
Flood Mitigation	Yes; flood control storage can be provided above the maximum extended detention volume	
[1] Change in event mean concentration (EMC) through the practice. The actual nutrient mass load removed is the product of the removal rate and the runoff reduction rate (see Table 1 in the *Introduction to the New Virginia Stormwater Design Specifications*).		

Sources: CWP and CSN (2008); CWP (2007)

SECTION 3: LEVEL 1 AND 2 DESIGN TABLE

The major design goal for ED Ponds in Virginia is to maximize nutrient removal and runoff reduction. To this end, designers may choose to go with the baseline design (Level 1) or choose an enhanced design (Level 2) that maximizes nutrient removal and runoff reduction. To qualify for the higher nutrient reduction rates associated with the Level 2 design, ED ponds must be designed with a Treatment Volume equal to $1.25(R_v)(A)$. **Table 14.2** lists the criteria for the Level 1 and 2 designs. See **Section 6** for more detailed design guidelines.

Table 15.2. Extended Detention (ED) Pond Criteria

Level 1 Design (RR:0; TP:15; TN:10)	Level 2 Design (RR:15; TP:15; TN:10)
T_V = [(1.0) (Rv) (A)] / 12 – the volume reduced by an upstream BMP	T_V = [(1.25) (R_V) (A)] / 12 – the volume reduced by an upstream BMP
A minumum of 15% of the T_V in the permanent pool (forebay, micropool)	A minumum of 40% of T_V in the permanent pool (forebay, micropool, or deep pool, or wetlands)
Length/Width ratio *OR* flow path = 2:1 or more	Length/Width ratio *OR* flow path = 3:1 or more
Length of the shortest flow path / overall length = 0.4 or more	Length of the shortest flow path / overall length = 0.7 or more
Average T_V ED time = 24 hours or less	Average T_V ED time = 36 hours
Vertical T_V ED fluctuation exceeds 4 feet	Maximum vertical T_V ED limit of 4 feet
Turf cover on floor	Trees and wetlands in the planting plan
Forebay and micropool	Incudes additional cells or features (deep pools, wetlands, etc.) Refer to Section 5
CDA is less than 10 acres	CDA is greater than 10 acres

SECTION 4: TYPICAL DETAILS

Figure 15.1 portrays a typical schematic for an ED pond.

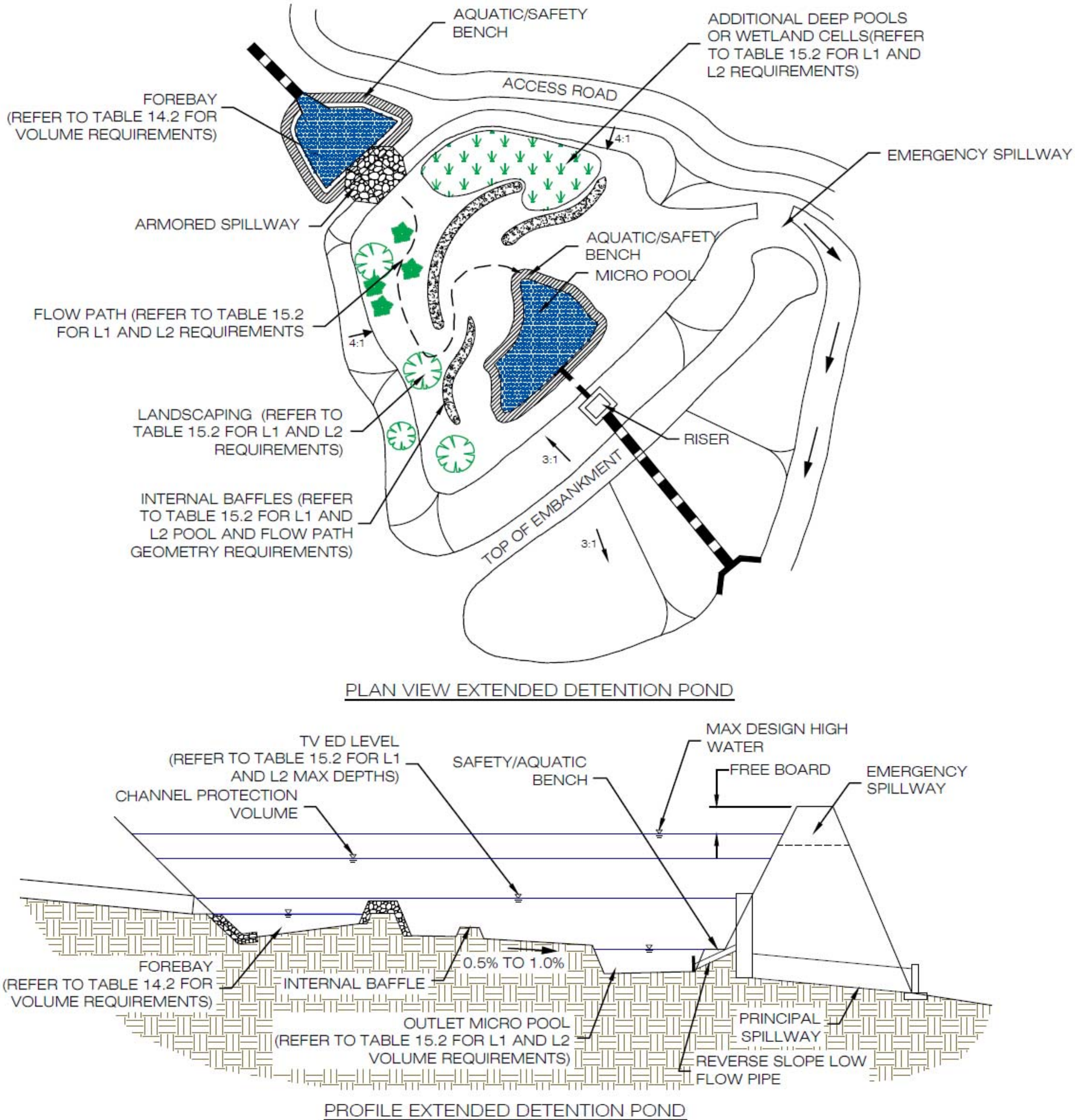


Figure 15.1. Typical Extended Detention Pond Details

SECTION 5: PHYSICAL FEASIBILITY & DESIGN APPLICATIONS

The following feasibility issues need to be evaluated when ED ponds are considered as the final practice in a treatment train. Many of these issues will be influenced by the type of ED Pond being considered (refer to Design Applications at the end of this section).

Space Required. A typical ED pond requires a footprint of 1% to 3% of its contributing drainage area, depending on the depth of the pond (i.e., the deeper the pond, the smaller footprint needed).

Contributing Drainage Area. A minimum contributing drainage area of 10 acres is recommended for ED ponds, in order to sustain a permanent micropool to protect against clogging. Extended detention may still work with drainage areas less than 10 acres, but designers should be aware that these “pocket” ponds will typically (1) have very small orifices that will be prone to clogging, (2) experience fluctuating water levels, and (3) generate more significant maintenance problems.

Available Hydraulic Head. The depth of an ED pond is usually determined by the amount of hydraulic head available at the site. The bottom elevation is normally the invert of the existing downstream conveyance system to which the ED pond discharges. Typically, a minimum of 6 to 10 feet of head is needed for an ED pond to function.

Minimum Setbacks. Local ordinances and design criteria should be consulted to determine minimum setbacks to property lines, structures, and wells. Generally, ED ponds should be set back at least 10 feet from property lines, 25 feet from building foundations, 50 feet from septic system fields, and 100 feet from private wells.

Depth-to-Water Table and Bedrock. ED ponds are not allowed if the water table or bedrock will be within 2 feet of the floor of the pond.

Soils. The permeability of soils is seldom a design constraint for micropool ED ponds. Soil infiltration tests need to be conducted at proposed pond sites to estimate infiltration rates, which can be significant in Hydrologic Soil Group (HSG) A soils and some group B soils. Infiltration through the bottom of the pond is encouraged unless it will impair the integrity of the embankment. Geotechnical tests should be conducted to determine the infiltration rates and other subsurface properties of the soils underlying the proposed ED pond. If the site is on karst topography, an alternative practice or combination of practices should be employed at the site, if possible. See Technical bulletin No. 1 (CSN, 2008) for guidance on stormwater design in karst terrain. The Extended Detention Basin should be the option of last resort and, if used in karst, must have an impermeable clay or (preferably) geosynthetic liner in accordance with Stormwater Design Specification No. 13 (Constructed Wetlands).

Trout Streams. Pond practices have a tendency to raise the water temperature in receiving streams. Therefore, the use of ED ponds in watersheds containing trout streams is restricted to situations where upland runoff reduction practices cannot meet the full Channel Protection Volume requirement. In these instances, a micrpool ED pond must (1) be designed with a maximum 12 hour detention time, (2) have a minimum pool volume sufficient to prevent clogging, (3) be planted with trees so it becomes fully shaded and (4) be located outside of any required stream buffers.

Perennial Streams. Locating dry ED ponds on perennial streams is strongly discouraged and will require both a Section 401 and Section 404 permit from the appropriate state or federal regulatory agency.

Design Applications

Extended Detention is normally combined with other stormwater treatment options within the stormwater facility (e.g., wet ponds, and constructed wetlands) to enhance its performance and appearance. Other design variations are also possible where a portion of the runoff is directed to bioretention, infiltration, sand filters, etc., that are within the overall footprint but housed in a separate cell, where the ponding depth of the Tv, channel protection storage, and/or flood protection storage is limited by the criteria of that particular practice. In such cases, the designer may need to develop a concept design and "hybrid" performance for review by the plan approving authority (or the Virginia BMP Clearinghouse, for broader application).

The typical design applications for ED include:

- Micropool Extended Detention
- Wet Extended Detention Pond (covered in Stormwater Design Specification No.14, Wet Ponds)
- Limited ED above Wetlands (covered Stormwater Design Specification No. 13, Constructed Wetlands)

Figure 15.1 above illustrates several ED pond design variations. While ED ponds can provide for channel and flood protection, they will rarely provide adequate runoff volume reduction and pollutant removal to serve as a stand-alone compliance strategy. Therefore, designers should always maximize the use of upland runoff reduction practices, (e.g., rooftop disconnections, small-scale infiltration, rainwater harvesting, bioretention, grass channels and dry swales) that reduce runoff at its source (rather than merely treating the runoff at the terminus of the storm drain system). Upland runoff reduction practices can be used to satisfy most or all of the runoff reduction requirements at most sites. However, an ED pond may still be needed to provide any remaining channel protection requirements. Upland runoff reduction practices will greatly reduce the size, footprint and cost of the downstream ED pond.

SECTION 6: DESIGN CRITERIA

6.1. Overall Sizing

Designers can use a site-adjusted R_v or CN to reflect the use of upland runoff reduction practices to compute the remaining treatment, channel protection, and/or flood protection volumes that must be treated by the ED pond, using the accepted applicable method. ED ponds are then designed to capture and treat the remaining runoff volume as necessary. Runoff treatment (T_v) credit may be taken for the entire water volume below the normal pool elevation of any micropools, forebays and wetland areas (minimum of 15% for ED Level 1, and 40% for Level 2), as well as the temporary extended detention above the normal pool. To qualify for the higher nutrient reduction rates associated with the Level 2 design, the ED pond must be designed with a Treatment Volume that is 25% greater than the T_v for the Level 1 design [i.e., $1.25(R_v)(A)$], but not any additional Channel Protection Volume.

6.2. Treatment Volume Drawdown and Detention Design

Methods for calculating the required orifice size for achieving the target drawdown of the Treatment Volume for the Level 1 (24 hours) and Level 2 (36 hours) design can be found in the Engineering Calculations chapter of the current Virginia Stormwater Management Handbook. Similarly, the hydraulic design of the multi-stage riser to meet the channel protection and flooding protection design goals can also be found in the Virginia Stormwater Management Handbook.

Refer to Table 15.2 for the Level 1 and Level 2 maximum ponding depths and other criteria.

6.3. Required Geotechnical Testing

Soil borings should be taken below the proposed embankment, in the vicinity of the proposed outlet area, and in at least two locations within the proposed ED pond treatment area. Soil boring data is needed to (1) determine the physical characteristics of the excavated material, (2) determine its adequacy for use as structural fill or spoil, (3) provide data for structural designs of the outlet works (e.g., bearing capacity and buoyancy), (4) determine compaction/composition needs for the embankment, (5) determine the depth to groundwater and bedrock and (6) evaluate potential infiltration losses (and the potential need for a liner).

6.4. Pretreatment Forebay

Sediment forebays are considered to be an integral design feature to maintain the longevity of ED ponds. A forebay must be located at each major inlet to trap sediment and preserve the capacity of the main treatment cell. Other forms of pre-treatment for sheet flow and concentrated flow for minor inflow points should be designed consistent with pretreatment criteria found in Design Spec No. 9: Bioretention. The following criteria apply to forebay design:

- A major inlet is defined as an individual storm drain inlet pipe or open channel serving at least 10% of the ED pond's contributing drainage area.
- The forebay consists of a separate cell, formed by an acceptable barrier. (e.g., an earthen berm, concrete weir, gabion baskets, etc.).
- The forebay should be at least 4 feet deep and must be equipped with a variable width aquatic bench for safety purposes. The aquatic benches should be 4 to 6 feet wide at a depth of 18 inches below the water surface.
- The total volume of all forebays should be at least 15% of the total Treatment Volume (inclusive – and thereby satisfying the Level 1 permanent pool volume requirement – however, a micro pool outlet is still encouraged for maintenance benefits). The relative size of individual forebays should be proportional to the percentage of the total inflow to the

wetland. Similarly, any outlet protection associated with the end section or end wall should be designed according to state or local design standards.

- The forebay should be designed in such a manner that it acts as a level spreader to distribute runoff evenly across the entire bottom surface area of the main treatment cell.
- The bottom of the forebay may be hardened (e.g., concrete, asphalt, or grouted riprap) in order to make sediment removal easier.
- The forebay should be equipped with a metered rod in the center of the pool (as measured lengthwise along the low flow water travel path) for long-term monitoring of sediment accumulation.

6.5. Conveyance and Overflow

No Pilot Channels. Micropool ED ponds shall not have a low flow pilot channel, but instead must be constructed in a manner whereby flows are evenly distributed across the pond bottom, to promote the maximum infiltration possible.

Internal Slope. The maximum longitudinal slope through the pond should be approximately 0.5% to 1% to promote positive flow through the ED pond.

Primary Spillway. The primary spillway shall be designed with acceptable anti-flotation, anti-vortex, and trash rack devices. The spillway must generally be accessible from dry land. **Appendix B: Principal Spillways** of the *Introduction to the New Virginia Stormwater Design Specifications*, as posted on the Virginia Stormwater BMP Clearinghouse web site, at the following web site:

http://www.vwrrc.vt.edu/swc/NonProprietaryBMPs.html

Non-Clogging Low Flow Orifice. ED Ponds with drainage areas of 10 acres or less, where small diameter pipes are typical, are prone to chronic clogging by organic debris and sediment. Orifices less than 3 inches in diameter may require extra attention during design to minimize the potential for clogging. Designers should always look at upstream conditions to assess the potential for higher sediment and woody debris loads. The risk of clogging in outlet pipes with small orifices can be reduced by:

- Providing a micropool at the outlet structure:
  - Use a reverse-sloped pipe that extends to a mid-depth of the permanent pool or micropool.
  - Install a downturned elbow or half-round CMP over a riser orifice (circular, rectangular, V-notch, etc.) to pull water from below the micropool surface.
  - The depth of the micropool should be at least 4 feet deep, and the depth may not draw down by more than 2 feet during a 30 day summer drought (for a water balance calculation method, see Section 6.2 of Stormwater Design Specification No 13: Constructed Wetlands).
- Providing an over-sized forebay to trap sediment, trash and debris before it reaches the ED pond's low-flow orifice.
- Installing a trash rack to screen the low-flow orifice.

- Using a perforated pipe under a gravel blanket with an orifice control at the end in the riser structure to supplement the primary outlet.

Emergency Spillway. ED ponds must be constructed with overflow capacity to pass the 100-year design storm event through either the Primary Spillway or a vegetated or armored Emergency Spillway. **Appendix C: Emergency Spillways** of the *Introduction to the New Virginia Stormwater Design Specifications*, as posted on the Virginia Stormwater BMP Clearinghouse web site (the URL is on the previous page).

Adequate Outfall Protection. The design must specify an outfall that will be stable for the 10-year design storm event. The channel immediately below the pond outfall must be modified to prevent erosion and conform to natural dimensions in the shortest possible distance. This is typically done by placing appropriately sized riprap, over filter fabric, which can reduce flow velocities from the principal spillway to non-erosive levels (3.5 to 5.0 fps depending on the channel lining material). Flared pipe sections that discharge at or near the stream invert or into a step pool arrangement should be used at the spillway outlet.

Inlet Protection. Inlet areas should be stabilized to ensure that non-erosive conditions exist during storm events up to the overbank flood event (i.e., the 10-year storm event). Inlet pipe inverts should generally be located at or slightly below the forebay pool elevation.

On-Line ED Ponds must be designed to detain the required T_v and either manage or be capable of safely passing larger storm events conveyed to the pond (e.g., 1-year channel protection detention, 10-year flood protection, and/or the 100-year design storm event). Adequate design freeboard between the maximum design water surface elevation and the top of the embankment must be provided in accordance with Design Specification **Appendix A: Earthen Embankments** of the *Introduction to the New Virginia Stormwater Design Specifications*, as posted on the Virginia Stormwater BMP Clearinghouse web site, at the following web site:

http://www.vwrrc.vt.edu/swc/NonProprietaryBMPs.html

Dam Safety Permits. ED ponds with high embankments or large drainage areas and impoundments may may be regulated under the Virginia Dam Safety Act (§ 10.1-606.1 et seq., Code of Virginia) and the Virginia Dam Safety Regulations (4 VAC 50-20 et seq.). Refer to Design Specification Appendix A: Earthen Embankments for additional information.

6.6. Internal Design Features

Side Slopes. Side slopes leading to the ED pond should generally have a gradient of 4H:1V to 5H:1V. The mild slopes promote better establishment and growth of vegetation and provide for easier maintenance and a more natural appearance.

Long Flow Path. ED pond designs should have an irregular shape and a long flow path from inlet to outlet to increase water residence time, treatment pathways, and pond performance. In terms of flow path geometry, there are two design considerations: (1) the overall flow path through the pond, and (2) the length of the shortest flow path (Hirschman et al., 2009):

- The overall flow path can be represented as the length-to-width ratio *OR* the flow path ratio (see the *Introduction to the New Virginia Stormwater Design Specifications*, as posted on the Virginia Stormwater BMP Clearinghouse web site for diagrams and equations). These ratios must be at least 2L:1W for Level 1 designs and 3L:1W for Level 2 designs. Internal berms, baffles, or topography can be used to extend flow paths and/or create multiple pond cells.
- The shortest flow path represents the distance from the closest inlet to the outlet (the *Introduction to the New Virginia Stormwater Design Specifications*, as posted on the Virginia Stormwater BMP Clearinghouse web site). The ratio of the shortest flow to the overall length must be at least 0.4 for Level 1 designs and 0.7 for Level 2 designs. In some cases – due to site geometry, storm sewer infrastructure, or other factors – some inlets may not be able to meet these ratios. However, the drainage area served by these “closer” inlets should constitute no more than 20% of the total contributing drainage area.

Treatment Volume (water quality) Storage. The total T_v storage may be provided by a combination of the permanent pool (in the form of forebays, deep pools, and/or wetland area) and extended detention storage in accordance with the Level 1 and Level 2 design volume allocations.

Vertical Extended Detention Limits. The maximum T_v (1 inch) ED water surface elevation may not extend more than 5 feet above the basin floor or normal pool elevation for a Level 1 design, or 4 feet for a Level 2 design.. The maximum vertical elevation for ED and channel protection detention over shallow wetlands is 1 foot. The bounce effect is not as critical for larger flood control storms (e.g., the 10-year design storm), and these events can exceed the 5 foot vertical limit if they are managed by a multi-stage outlet structure.

Safety Features.

- The principal spillway opening must be designed and constructed to prevent access by small children.
- End walls above pipe outfalls greater than 48 inches in diameter must be fenced to prevent a hazard.
- An emergency spillway and associated freeboard must be provided in accordance with applicable local or state dam safety requirements. The emergency spillway must be located so that downstream structures will not be impacted by spillway discharges.
- Both the safety bench and the aquatic bench should be landscaped with vegetation that hinders or prevents access to the pool.

6.7. Landscaping and Planting Plan

A landscaping plan must be provided that indicates the methods used to establish and maintain vegetative coverage within the ED pond and its buffer. Minimum elements of a plan include the following:

- Delineation of pondscaping zones within both the pond and buffer
- Selection of corresponding plant species
- The planting plan

- The sequence for preparing the wetland bed, if one is incorporated with the ED pond (including soil amendments, if needed)
- Sources of native plant material
- The landscaping plan should provide elements that promote diverse wildlife and waterfowl use within the stormwater wetland and buffers.
- The planting plan should allow the pond to mature into a native forest in the right places, but yet keep mowable turf along the embankment and all access areas. The wooded wetland concept proposed by Cappiella *et al*., (2005) may be a good option for many ED ponds.
- Woody vegetation may not be planted or allowed to grow within 15 feet of the toe of the embankment nor within 25 feet from the principal spillway structure.
- A buffer should be provided that extends
- A vegetated buffer should be provided that extends at least 25 feet outward from the maximum water surface elevation of the ED pond. Permanent structures (e.g., buildings) should not be constructed within the buffer area. Existing trees should be preserved in the buffer area during construction.
- The soils in the stormwater buffer area are often severely compacted during the construction process, to ensure stability. The density of these compacted soils can be so great that it effectively prevents root penetration and, therefore, may lead to premature mortality or loss of vigor. As a rule of thumb, planting holes should be three times deeper and wider than the diameter of the rootball for ball-and-burlap stock, and five times deeper and wider for container-grown stock.
- Avoid species that require full shade, or are prone to wind damage. Extra mulching around the base of trees and shrubs is strongly recommended as a means of conserving moisture and suppressing weeds.

For more guidance on planting trees and shrubs in ED pond buffers, consult Cappiella et al (2006) and **Appendix E: Landscaping** of the *Introduction to the New Virginia Stormwater Design Specifications* , as posted on the Virginia Stormwater BMP Clearinghouse web site.

6.8. Maintenance Reduction Features

Good maintenance access is needed so crews can remove sediments from the forebay, alleviate clogging and make riser repairs. The following ED pond maintenance issues can be addressed during design, in order to make on-going maintenance easier:

- Adequate maintenance access must extend to the forebay, micropool, any safety benches, riser, and outlet structure and must have sufficient area to allow vehicles to turn around.
- The riser should be located within the embankment for maintenance access, safety and aesthetics. Access to the riser should be provided by lockable manhole covers and manhole steps within easy reach of valves and other controls.
- Access roads must (1) be constructed of load-bearing materials or be built to withstand the expected frequency of use, (2) have a minimum width of 12 feet, and (3) have a profile grade that does not exceed 15%. Steeper grades are allowable if appropriate stabilization techniques are used, such as a gravel road.
- A maintenance right-of- way or easement must extend to the ED pond from a public or private road.

- The designer should check to see whether sediments can be spoiled (deposited) on-site or must be hauled away.

6.9. ED Pond Material Specifications

ED ponds are generally constructed with materials obtained on-site, except for the plant materials, inflow and outflow devices (e.g., piping and riser materials), possibly stone for inlet and outlet stabilization, and filter fabric for lining banks or berms.

The basic material specifications for earthen embankments, principal spillways, vegetated emergency spillways and sediment forebays shall be as specified in **Appendices A through D** of the *Introduction to the New Virginia Stormwater Design Specifications* , as posted on the Virginia Stormwater BMP Clearinghouse web site, at the following URL:

http://www.vwrrc.vt.edu/swc/NonProprietaryBMPs.html

When reinforced concrete pipe is used for the principal spillway to increase its longevity, "O"-ring gaskets (ASTM C-361) should be used to create watertight joints, and they should be inspected during installation.

SECTION 7: REGIONAL & SPECIAL CASE DESIGN ADAPTATIONS

7.1. Karst Terrain

Karst regions are found in much of the Ridge and Valley province of the Virginia. The presence of karst complicates both land development in general and stormwater design in particular. Designers should always conduct geotechnical investigations in karst terrain to assess this risk during the project planning stage. Because of the risk of sinkhole formation and groundwater contamination in karst regions, *use of ED ponds is highly restricted there* (see CSN Technical Bulletin No. 1, 2008, and Appendix 6-C of Chapter 6 of the Virginia Stormwater Management Handbook, 2010). If these studies indicate that less than 3 feet of vertical separation exists between the bottom of the ED pond and the underlying soil-bedrock interface, ED ponds should not be used. If ED ponds are used, they must have an acceptable liner in accordance with the guidance provided in Section 7.1 of Stormwater Design Specification No. 13 (Constructed Wetlands).

7.2. Coastal Plain

The lack of sufficient hydraulic head and the presence of a high water table of many coastal plain sites significantly constrain the application of ED ponds. Excavating ponds below the water table creates what are known as dugout ponds where the water quality volume is displaced by groundwater, reducing the pond's mixing and treatment efficiency and creating nuisance conditions. In general, ***shallow constructed wetlands are a superior alternative to ED ponds in coastal plain settings***.

7.3. Steep Terrain

The use of ED ponds is highly constrained at development sites with steep terrain.

7.4. Cold Climate and Winter Performance

Winter conditions can cause freezing problems within inlets, flow splitters, and ED outlet pipes, due to ice formation. The following design adjustments are recommended for ED ponds installed in higher elevations and colder climates:

- Do not submerge inlet pipes.
- Provide a minimum 1% slope for inlet pipes to discourage standing water and potential ice formation in upstream pipes.
- Place all pipes below the frost line to prevent frost heave and pipe freezing.
- Locate low flow orifices in the micropool so they withdraw at least 6 inches below the typical ice layer.
- Place trash racks at a shallow angle to prevent ice formation.
- If winter road sanding is prevalent in the contributing drainage area, increase the forebay size to 25% of the total Treatment Volume to accommodate additional sediment loadings.

7.5. Linear Highway Sites

ED ponds are poorly suited to treat runoff within open channels located in the highway right of way, unless storage is available in a cloverleaf interchange or in an expanded right-of-way. Guidance for pond construction in these areas is provided in VDOT's annually stormwater management specifications, as reviewed and approved annually by DEQ. Additional guidance can be found in Profile Sheet SR-5 in Schueler et al (2007).

SECTION 8: CONSTRUCTION

8.1. Construction Sequence

The following is a typical construction sequence to properly install a dry ED pond. The steps may be modified to reflect different dry ED pond designs, site conditions, and the size, complexity and configuration of the proposed facility.

Step 1: Use of ED pond as an E&S Control. An ED pond may serve as a sediment basin during project construction. If this is done, the volume should be based on the more stringent sizing rule (erosion and sediment control requirement vs. water quality treatment requirement). Installation of the permanent riser should be initiated during the construction phase, and design elevations should be set with final cleanout of the sediment basin and conversion to the post-construction ED pond in mind. The bottom elevation of the ED pond should be lower than the bottom elevation of the temporary sediment basin. Appropriate procedures should be implemented to prevent discharge of turbid waters when the basin is being converted into an ED pond.

Step 2: Stabilize the Drainage Area. ED ponds should only be constructed after the contributing drainage area to the pond is completely stabilized. If the proposed pond site will be used as a sediment trap or basin during the construction phase, the construction notes should clearly indicate that the facility will be dewatered, dredged and re-graded to design dimensions after the original site construction is complete.

Step 3: Assemble Construction Materials on-site, make sure they meet design specifications, and prepare any staging areas.

Step 4: Clear and Strip the project area to the desired sub-grade.

Step 5: Install E&S Controls prior to construction, including temporary de-watering devices and stormwater diversion practices. All areas surrounding the pond that are graded or denuded during construction must be planted with turf grass, native plantings, or other approved methods of soil stabilization.

Step 6: Excavate the Core Trench and Install the Spillway Pipe.

Step 7: Install the Riser or Outflow Structure and ensure the top invert of the overflow weir is constructed level at the design elevation.

Step 8: Construct the Embankment and any Internal Berms in 8 to 12-inch lifts and compact the lifts with appropriate equipment.

Step 9: Excavate/Grade until the appropriate elevation and desired contours are achieved for the bottom and side slopes of the ED pond.

Step 10: Construct the Emergency Spillway in cut or structurally stabilized soils.

***Step 11: Install Outlet Pipe*s**, including downstream rip-rap apron protection.

Step 12: Stabilize Exposed Soils with temporary seed mixtures appropriate for the pond buffer. All areas above the normal pool elevation should be permanently stabilized by hydroseeding or seeding over straw.

Step 13: Plant the Pond Buffer Area, following the pondscaping plan (see **Section 8.5** below).

8.2. Construction Inspection

Multiple inspections are critical to ensure that stormwater ponds are properly constructed. Inspections are recommended during the following stages of construction:

- Pre-construction meeting
- Initial site preparation (including installation of E&S controls)
- Excavation/Grading (interim and final elevations)
- Installation of the embankment, the riser/primary spillway, and the outlet structure

- Implementation of the pondscaping plan and vegetative stabilization
- Final inspection (develop a punchlist for facility acceptance)

A construction phase inspection checklist for Extended Detention Ponds can be accessed at the CWP website at:

http://www.cwp.org/Resource_Library/Controlling_Runoff_and_Discharges/sm.htm
(scroll to Tool6: Plan Review, BMP Construction, and Maintenance Checklists)

For larger ED ponds, use the expanded construction inspection form provided in Appendix B of CWP (2004).

If the ED pond has a permanent pool, then to facilitate maintenance the contractor should measure the actual constructed pond depth at three areas within the permanent pool (forebay, mid-pond and at the riser), and they should mark and geo-reference them on an as-built drawing. This simple data set will enable maintenance inspectors to determine pond sediment deposition rates in order to schedule sediment cleanouts.

SECTION 9: MAINTENANCE

9.1. Maintenance Agreements

Section 4 VAC 50-60-124 of the regulations specifies the circumstances under which a maintenance agreement ~~to~~ must be executed between the owner and the local program. This section sets forth inspection requirements, compliance procedures if maintenance is neglected, notification of the local program upon transfer of ownership, and right-of-entry for local program personnel. Access to ED ponds should be covered by a drainage easement to allow inspection and maintenance.

It is also recommended that the maintenance agreement include a list of qualified contractors that can perform inspection or maintenance services, as well as contact information for owners to get local or state assistance to solve common nuisance problems, such as mosquito control, geese, invasive plants, vegetative management and beaver removal. The CWP *Pond and Wetland Maintenance Guidebook* (2004) provides some excellent templates of how to respond to these problems.

9.2. Maintenance Inspections

Maintenance of ED ponds is driven by annual inspections that evaluate the condition and performance of the pond, including the following:

- Measure sediment accumulation levels in forebay.
- Monitor the growth of wetlands, trees and shrubs planted. Record the species and their approximate coverage, and note the presence of any invasive plant species.
- Inspect the condition of stormwater inlets to the pond for material damage, erosion or undercutting.

- Inspect the banks of upstream and downstream channels for evidence of sloughing, animal burrows, boggy areas, woody growth, or gully erosion that may undermine embankment integrity.
- Inspect pond outfall channel for erosion, undercutting, rip-rap displacement, woody growth, etc.
- Inspect condition of principal spillway and riser for evidence of spalling, joint failure, leakage, corrosion, etc.
- Inspect condition of all trash racks, reverse sloped pipes or flashboard risers for evidence of clogging, leakage, debris accumulation, etc.
- Inspect maintenance access to ensure it is free of woody vegetation, and check to see whether valves, manholes and locks can be opened and operated.
- Inspect internal and external side slopes of the pond for evidence of sparse vegetative cover, erosion, or slumping, and make needed repairs immediately.

Based on inspection results, specific maintenance tasks will be triggered. Example maintenance inspection checklists for Extended Detention Ponds can be accessed in Appendix C of Chapter 9 of the *Virginia Stormwater Management Handbook* (2010) or at the CWP website at:

http://www.cwp.org/Resource_Library/Controlling_Runoff_and_Discharges/sm.htm
(scroll to Tool6: Plan Review, BMP Construction, and Maintenance Checklists)

For a more detailed maintenance inspection checklist, see Appendix B in CWP *Stormwater Pond and Wetland Maintenance Guidebook* (2004).

9.3. Common Ongoing Maintenance Issues

ED ponds are prone to a high clogging risk at the ED low-flow orifice. This component of the pond's plumbing should be inspected at least twice a year after initial construction. The constantly changing water levels in ED ponds make it difficult to mow or manage vegetative growth. The bottom of ED ponds often become soggy, and water-loving trees such as willows may take over. The maintenance plan should clearly outline how vegetation in the pond and its buffer will be managed or harvested in the future. Periodic mowing of the stormwater buffer is only required along maintenance rights-of-way and the embankment. The remaining buffer can be managed as a meadow (mowing every other year) or forest.

The maintenance plan should schedule a shoreline cleanup at least once a year to remove trash and floatables that tend to accumulate in the forebay, micropool, and on the bottom of ED ponds.

Frequent sediment removal from the forebay is essential to maintain the function and performance of an ED pond. Maintenance plans should schedule cleanouts every 5 to 7 years, or when inspections indicate that 50% of the forebay capacity has been filled. As noted above, the designer should also check to see whether removed sediments can be spoiled (deposited) on-site or must be hauled away. Sediments excavated from ED ponds are not usually considered toxic or hazardous, and can be safely disposed by either land application or land filling.

SECTION 10: COMMUNITY AND ENVIRONMENTAL CONCERNS

Extended Detention Ponds can generate the following community and environmental concerns that need to be addressed during design.

Aesthetics. ED ponds tend to accumulate sediment and trash, which residents are likely to perceive as unsightly and creating nuisance conditions. Fluctuating water levels in ED ponds also create a difficult landscaping environment. In general, designers should avoid designs that rely solely on *dry* ED ponds.

Existing Wetlands. ED ponds should never be constructed within existing *natural* wetlands, nor should they inundate or otherwise change the hydroperiod of existing wetlands.

Existing Forests. Designers can expect a great deal of neighborhood opposition if they do not make a concerted effort to save mature trees during design and pond construction. Designers should also be aware that even modest changes in inundation frequency can kill upstream trees (Wright *et al.,* 2007).

Stream Warming Risk. ED ponds have less risk of stream warming than other pond options, but they can warm streams if they are unshaded or contain significant surface area in shallow pools. If an ED pond discharges to temperature-sensitive waters, it should be forested, contain the minimum pools to prevent clogging, and have a detention time of no longer than 12 hours.

Safety Risk. ED ponds are generally considered to be safer than other pond options, since they have few deep pools. Steep side-slopes and unfenced headwalls, however, can still create some safety risks. Gentle side slopes should be provided to avoid potentially dangerous drop-offs, especially where ED ponds are located near residential areas.

Mosquito Risk. The fluctuating water levels within ED ponds have potential to create conditions that lead to mosquito breeding. Mosquitoes tend to be more prevalent in irregularly flooded ponds than in ponds with a permanent pool (Santana *et al*., 1994). Designers can minimize the risk by combining ED with a wet pond or wetland.

SECTION 11: REFERENCES

Cappiella, K., T. Schueler and T. Wright. 2006. *Urban Watershed Forestry Manual: Part 2: Conserving and Planting Trees at Development Sites*. USDA Forest Service. Center for Watershed Protection. Ellicott City, MD.

Cappiella, K. et al . 2007. *Urban Watershed Forestry Manual: Part 3: Urban Tree Planting Guide*. USDA Forest Service. Center for Watershed Protection. Ellicott City, MD.

Cappiella, K., L. Fraley-McNeal, M. Novotney and T. Schueler. 2008. "The Next Generation of Stormwater Wetlands." *Wetlands and Watersheds Article No. 5.* Center for Watershed Protection. Ellicott City, MD.

Center for Watershed Protection. 2004. *Pond and Wetland Maintenance Guidebook*. Ellicott City, MD.

Hirschman, D., L. Woodworth and S. Drescher. 2009. *Technical Report: Stormwater BMPs in Virginia's James River Basin: An Assessment of Field Conditions & Programs*. Center for Watershed Protection. Ellicott City, MD.

Maryland Department of Environment (MDE). 2000. *Maryland Stormwater Design Manual*. Baltimore, MD. Available online at: http://www.mde.state.md.us/Programs/WaterPrograms/SedimentandStormwater/stormwater_design/index.asp

Schueler, T., D. Hirschman, M. Novotney and J. Zielinski. 2007. *Urban Stormwater Retrofit Practices*. Manual 3 in the Urban Subwatershed Restoration Manual Series. Center for Watershed Protection, Ellicott City, MD.

Virginia Stormwater Management Handbook. 1999. *Volumes 1 and 2*. Richmond, VA.

APPENDIX A

EARTHEN EMBANKMENT

VERSION 1.0
March 1, 2011

SECTION A-1: DESCRIPTION OF PRACTICE

An earthen embankment is a raised impounding structure made from compacted soil. The embankment is the feature of pond-type practices that causes the impoundment of water.

SECTION A-2: PERFORMANCE CRITERIA

Not applicable

SECTION A-3: PRACTICE APPLICATIONS AND FEASIBILITY

An earthen embankment is appropriate for use with infiltration, detention, extended-detention, retention or constructed wetland facilities.

The design procedures presented in this section **may not** apply to small embankments or to storm drainage outfall structures with less than 3 feet of embankment height. The review and approval of such structures should be based on sound engineering practices and supporting calculations that verify a stable outfall for the 10-year storm, at a minimum.

Similarly, this section **does not** apply to embankments with a height of 25 feet or more and a maximum storage capacity of 50 acre-feet or more, as measured from the top of the embankment. Such structures may be regulated under the Virginia Dam Safety Act (§ 10.1-606.1 et seq., Code of Virginia) and the Virginia Dam Safety Regulations (4 VAC 50-20 et seq.).

The *height of an earthen embankment* is the vertical distance from the natural bed of the stream or watercourse, measured at the downstream toe of the embankment, to the top of the embankment. If the embankment does not span a stream or watercourse, the height is the vertical distance between the lowest elevation, measured at the outside limit of the embankment, and the top of the embankment.

SECTION A-4: ENVIRONMENTAL AND COMMUNITY CONSIDERATIONS

Not applicable.

SECTION A-5: DESIGN APPLICATIONS AND VARIATIONS

Not applicable.

SECTION A-6: SIZING AND TESTING GUIDELINES

Not applicable.

SECTION A-7: DESIGN CRITERIA

Earthen embankments are complex structures that must be designed and constructed with consideration given to the following: (a) *specific site and foundation conditions*, (b) *construction material characteristics*, (c) *purpose of the impoundment*, and (d) *hazard potential associated with the particular site and/or impoundment*.

The *hazard potential* associated with an impoundment is defined in the Virginia Dam Safety Regulations. It is based on the potential for loss of life and/or economic loss due to facility failure. While stormwater management embankments are typically much smaller than those regulated under the Virginia Dam Safety Program, the potential for significant property damage and loss of life may still be present. The engineer is responsible for analyzing potential downstream impacts and for determining if more stringent analyses are required. **Minimum** guidelines for those facilities **not covered** under Virginia's Dam Safety Regulations are provided in this handbook.

Embankment Types

The type of embankment selected will depend on the purpose of the stormwater facility (detention, extended-detention, retention, etc.) and the available soil material for construction. The two general types are listed below:

1. A *homogeneous embankment* is composed of one kind of material (excluding slope protection). The material used must be sufficiently impervious to provide an adequate water barrier, and the slopes must be moderately flat for stability and ease of maintenance (see **Figure A-1a**).

2. A *zoned embankment* contains a central impervious core, flanked by zones of more pervious material called shells. These pervious zones or shells enclose, support, and protect the impervious core. Typically, a zoned embankment requires an internal drain, or filter, between the impervious zone and the downstream shell and between the shell and the foundation (see **Figure A-1b)**.

Soils Investigation

A soils investigation, or geotechnical study, should be completed before designing any earthen embankment covered in this section. The scope of such a study will vary from site to site based upon the size of each project. Recommended minimum guidelines for a geotechnical study are provided below. Refer to U.S. Department of Interior (USDI), *Design of Small Dams*, latest edition, for additional information.

Geotechnical Guidelines

The following discussion presents minimum recommended criteria for the planning and design of earthen embankments. The designer is responsible for determining which of the guidelines are applicable to the specific project and for determining if any additional investigations are required.

The validity of the design depends on the thoroughness of the site investigation, the adequacy of the testing program, and the soundness of the designer's judgment. Design components based on quantitative soil tests, such as analyses of slope stability, seepage, and settlement, are not discussed herein, but they are necessary to design large dams. Such analyses will logically follow the selection of a preliminary design. Even for small earth dams that have a low hazard potential, the following criteria should be considered in a geotechnical report.

A geotechnical engineering study should evaluate the stability of the proposed embankment and should consist of (1) *a site investigation*, (2) *laboratory testing*, and (3) *an engineering analysis*.

1. A field investigation should include the review of available soils information and a

subsurface exploration. Test borings, test pits, or both, should be used to evaluate the foundations, abutments, borrow materials, reservoir area, embankment design and any other pertinent geological considerations. In areas underlain by Karst limestone, a subsurface profile using seismic or sonar technology should be considered to verify that subsurface anomalies do not exist. This type of subsurface investigation may also be recommended in areas known to have been previously mined for mineral extractions.

2. Laboratory testing should be completed to evaluate the various soils. At a minimum, an *index property test* should be completed to classify the soils following the Unified Soil Classification System. Shear strength, compressibility, and permeability testing may be required depending upon the size and complexity of the embankment and the nature of the site's subsurface conditions.

3. A geotechnical engineer should do an engineering analysis and present his or her findings, recommendations and comments on items such as: foundation materials and preparation; design of interior drainage features and filters; and geotechnical design of conduits/structures through the embankment, including seepage and stability analyses. The engineer should also provide a summary describing the soil types and rock strata encountered and explaining the laboratory tests and their results.

Stream Diversions

The design of some earthen embankments will require provisions for stream diversions around or through the embankment site during construction. A stream diversion can be accomplished by a variety of acceptable means, including open channels, conduits, coffer dams, and pumping. Occasionally, stream diversions may be required to meet additional requirements and/or to be permitted by agencies such as the U.S. Army Corps of Engineers, the Virginia Department of Environmental Quality, and/or the Virginia Marine Resources Commission. Refer to the Virginia Erosion and Sediment Control Handbook (VESCH), 1992 edition, for additional guidance on stream diversions.

To establish *design water surface elevations* and *spillway capacity* for earthen embankments, various hydrologic design methods and spillway storm frequencies may be used. Factors that affect their selection include: (a) *the purpose of the stormwater facility: flood control, water quality enhancement, and/or channel erosion control,* (b) *the contributing watershed size*, and (c) *local regulations*. Despite the design method selected or the frequency storm is used, **the embankment should always be analyzed to ensure safe passage of the maximum spillway design storm while maintaining its structural integrity and stability**. Furthermore, the embankment height should be set such that runoff from the spillway design storm can safely pass through one of the following spillways without overtopping the embankment:

- a natural or constructed spillway;
- a principal spillway; or
- a combination of a principal spillway and an emergency spillway.

Hydrologic and hydraulic methods are described in **Chapter 12** of the Virginia Stormwater Management Handbook (2009).

Local ordinances or watershed conditions may require a more stringent analysis of the embankment concerning overtopping or spillway capacity. The USDA-Natural Resource Conservation Service's (NRCS) *National Engineering Handbook* and the Virginia Dam Safety Regulations provide a classification of dams based on the *potential hazard* from failure. A dam failure analysis, or *breach analysis*, may be required to learn the extent of the potential hazard. Any dam breach analysis should use a method similar to the Army Corps of Engineers, NRCS (*TR-60*), National Weather Service, or that specified by the local authority.

<u>Embankment Stability</u>

An earthen embankment must be designed to be stable against any *force condition* or combination of *force conditions* that may develop during the life of the structure. Other than overtopping caused by inadequate spillway capacity, the three most critical conditions that may cause failure of the embankment are:

1. *Differential settlement* within the embankment or its foundation due to a variation in materials, a variation in embankment height, or compression of the foundation strata. Differential settlement may, subsequently, cause the formation of cracks through the embankment that are roughly parallel to the abutments. These cracks may concentrate seepage through the dam and lead to failure by internal erosion.

2. S*eepage* through the embankment and foundation. This condition may cause piping within the embankment or the foundation, or both.

3. S*hearing stresses* within the embankment and foundation due to the weight of the fill. If the shearing stress force exceeds the strength of the materials, sliding of the embankment or its foundation may occur, resulting in the displacement of large portions of the embankment.

The stability of an embankment and its side slopes is dependent on the following: (1) *construction materials*, (2) *foundation conditions*, (3) *embankment height and cross-section geometry*, (4) *normal and maximum pool levels*, and (5) *purpose of BMP: retention, detention, or extended-detention*. The embankment cross-section should be designed to provide an adequate factor of safety to protect against sliding, sloughing, or rotation in the embankment or foundation. USDA-NRCS's *TR-60* publication provides guidelines for slope stability analysis when required. The most important factors in determining the stability of an embankment are:

1. **Physical characteristics of the fill materials:** Soil classification for engineering uses can be found in the USDA-NRCS *Engineering Field Manual*, Chapter 4, and other references listed at the end of this section.

2. **Configuration of the site:** The height of the embankment may vary considerably throughout its length, so the total settlement of any given section of the embankment may differ from that of adjacent sections. The length of the embankment and slope of the abutments

profoundly influence the degree of differential settlement between adjacent sections of the embankment. As the length shortens and the abutments become steeper, differential settlement becomes more likely. (**Appendix B**, **Principal Spillway** discusses the use of a concrete cradle to protect the spillway barrel sections from separating due to the forces of differential settlement.)

3. **Foundation materials:** The character and distribution of the foundation material must be considered for its *shear strength*, *compressibility*, and *permeability*. Occasionally, the shear strength of the foundation may govern the choice of embankment slopes. Permeability and stratification of the foundation may dictate the need for a *zoned embankment*. Quite often, foundations contain compressible soils that settle under the weight of the embankment, although the shear strength of these soils is satisfactory. When such settlement occurs in the foundation, the embankment settles. This settlement is rarely uniform over the basal area of the embankment. Therefore, fill materials used on such sites must be sufficiently plastic to deform without cracking. (**Appendix B**, **Principal Spillway** discusses the use of a concrete cradle to protect the spillway barrel sections from separating due to the forces of differential settlement.)

A foundation composed of homogeneous soil is simple to evaluate; however, this condition rarely occurs in natural soil deposits. Most often, a stratified deposit composed of layers of several soil types is encountered. To determine the suitability of such a foundation, the following information becomes very important: (1) *the geologic history of the site*, (2) *the degree of stratification*, and (3) *the order in which materials occur within the stratification*. A complex, stratified foundation containing plastic or compressible soil should be investigated by an experienced engineer or geologist.

Foundation cutoff: A foundation cutoff trench of moderately impervious material should be provided under the embankment. The cutoff trench should be installed at or upstream of the dam's centerline, and should extend up the abutments to the 10-year water surface elevation.

The bottom of the cutoff trench should be wide enough to accommodate excavation, backfill and compaction equipment. The trench's minimum width and depth should be 4 feet and the side slopes should be no steeper than 1H:1V (refer to **Figures A-1a, A-1b** and **A-2**).

Rock foundations: The presence of rock in the embankment foundation area requires specific design and construction recommendations (provided in the geotechnical engineering analysis) to insure a proper bond between the foundation and the embankment.

Generally, no blasting should be permitted within 100 feet of the foundation and abutment area. If blasting is essential, it should be carried out under controlled conditions to reduce adverse effects on the rock foundation, such as over-blasting and opening fractures. This is especially critical in areas of Karst topography.

Embankment zoning and seepage: The stability of an embankment slope and the seepage pattern through it are greatly influenced by the *zoning of the embankment*. (Refer to **Embankment Types** above.) The position of the saturation line within a homogeneous embankment is theoretically independent of the type of soil used in it. Although soils vary greatly in regard to permeability, even the tightest clays are porous and cannot prevent water from seeping through them. **The rate of seepage through an embankment is dependent on the consistency of the reservoir level and the permeability of the embankment or core material**.

The upper surface of seepage is called the *phreatic surface* (zero pressure). In a cross-section, it is called the *phreatic line*. The position of the phreatic line in a retention basin embankment can be assumed to begin at the normal pool elevation on the upstream slope and extend at a 4H:1V slope downward through the embankment. **This assumption is based on the presence of a permanent pool**. For detention and extended-detention facilities with no permanent pool, many designers assume that the embankment will not impound water long enough for a phreatic surface to occur. This assumption, however, is based on a properly designed, constructed, and maintained embankment. Many jurisdictions, therefore, have chosen a conservative design approach by requiring that the phreatic linestart at the 10-year design storm water surface elevation, regardless of the presence of a permanent pool.

For most stormwater management facilities, determining the location of the phreatic surface will often suggest the need to install seepage collars on the barrel. (Refer to **Appendix A-2, Principal Spillway**, for a discussion on seepage control along conduits.) For larger stormwater facilities, especially those with a permanent pool, the location of the phreatic surface may require additional design considerations such as an internal drain.

If the saturation line intersects the downstream slope of the embankment at a point above the toe, then seepage will exit the embankment along the downstream face and toe. Typically, the quantity of seepage is so slight that it does not affect the slope's stability. However, sometimes the saturation of the toe will cause sloughing or serious reduction of the shear strength in the downstream section of the embankment. Seepage control should be included in the design if the following conditions exist:

- Pervious layers in the foundation are not intercepted by the cutoff,
- Possible seepage from the abutments may create a wet embankment,
- The phreatic line intersects the downstream slope, or
- Special conditions exist which require drainage to insure a stable embankment.

For *seepage collar design*, it is recommended that the phreatic line start at the 10-year design storm water surface elevation and extend through the embankment at a 4H:1V slope. **If the phreatic line intersects the downstream slope, a qualified soil scientist should be consulted to decide if additional controls are needed**. The location of the phreatic surface, therefore, may have a significant impact on the design of the embankment.

Seepage may be controlled by:

- Foundation, abutment or embankment drains,
- A downstream drainage blanket,
- A downstream toe drain, or
- A combination of these measures (see **Figure A-1b**).

Foundation drains may control seepage encountered in the cutoff trench during construction. These drains must be downstream of the embankment centerline and outside the limits of the proposed cutoff trench.

Including a toe drain in the design of most homogeneous embankments may be desirable. Embankments built on pervious foundations or constructed of materials that exhibit susceptibility to piping and cracking should always be protected by adequate toe drainage. Toe drains may be constructed of sand, gravel, or rock, depending on the nature of the embankment fill material. Whenever a rock toe drain is installed, a graded filter should be placed between the fill and the drain. Often, a 12-inch layer of well-graded, stream-run, sandy gravel will satisfy this requirement. Filter and drainage diaphragm design criteria are presented in the references listed as USDA-NRCS Soil Mechanics Notes No. 1 and No. 3 at the end of this section, and provided in **Chapter 13 Appendix 13-B**.

Piping

The contact areas between the embankment soils, foundation material, abutments, and conduits are the most susceptible locations for *piping failures.* Piping occurs due to the variation in materials at contact points and the difficulty in compacting the soil in these areas. Compaction is especially difficult next to and under conduits and seepage collars. Therefore, it is highly recommended that all utility conduits, except the principal spillway, be installed away from the embankment. When utility conduits through the embankment cannot be avoided, they should meet the requirements for spillways, i.e., watertight joints, no gravel bedding, restrained to prevent joint separation due to settlement, etc.

Seepage along pipe conduits that extend through an embankment should be controlled by use of the following:

- Anti-seep collars, or
- Filter and drainage diaphragms.

Refer to **Appendix A-2, Principal Spillway** for additional information on the use of anti-seep collars. Filter and drainage diaphragms are presented in USDA-SCS Soil Mechanics Notes No. 1 and No. 3, available upon request from DEQ or USDA-SCS. When filter and drainage diaphragms are used, their design and construction should be supervised by a registered professional engineer.

Embankment Geometry

1. **Height:** The height of an earthen embankment is based upon the freeboard requirements relative to the maximum water surface elevation during the 100-year frequency storm event. **An embankment with an emergency spillway must provide at least 1 foot of freeboard from the maximum 100-year storm water surface elevation (WSE) to the lowest point on the top of the embankment (excluding the emergency spillway)**. (Note that the *spillway design storm W.S.E,* if specified, may be used instead of the 100-year elevation.)

An embankment without an emergency spillway must provide at least 2 feet of freeboard from the maximum 100-year storm WSE to the lowest point on the top of the embankment. (Note that the *spillway design storm WSE*, if specified, may be used instead of the 100-year elevation.)

2. **Top Width:** The top of an earthen embankment should be shaped to provide positive drainage. The top width is based on the following table:

Table A-1: Embankment Top Widths

Total Height of Embankment (*ft.*)	Minimum Top Width (*ft.*)
14 or less	8
15-19	10
20-24	12
25 or more	15

Compacted Fill

Using the Unified Soil Classification System, as covered in the geotechnical analysis, should specify the soil types.

The compaction requirements should include the percent of maximum dry density for the specified density standard, allowable range of moisture content, and maximum loose lift thickness. Refer to **Construction Specifications for Earthen Embankments** later in this standard. In general, the design of an embankment should account for approximately 10% settlement unless otherwise specified by a geotechnical report based on the embankment foundation and fill material. The top of the embankment must be level in order to avoid possible overtopping in one location in cases of extreme storms or spillway failure.

Compaction tests should be performed regularly throughout the embankment construction; typically, one test per 5,000 square feet on each layer of fill or as directed by the geotechnical engineer. Generally, one of two compaction tests will be specified for embankment construction: the *Standard Proctor Test* (ASTM D698) or the *Modified Proctor Test* (ASTM D1557). For the construction of earth dams, the Modified Proctor Test is likely to be more appropriate (Terzaghi, Peck, 1948).This is due in part to the unconfined nature of the earth fill for dam construction. A new Proctor test is required if the material changes from that previously tested.

Embankment Construction

A geotechnical or construction inspector should be on site during embankment construction. Inspectors should be required to do more than just test fill compaction, i.e., observe foundation preparation, pipe installation, riser construction, filter installation, etc. (Refer to inspection checklist for impoundment structures, **Appendix F**).

A vertical trench through the embankment material should not be allowed under any circumstances in order to place the spillway pipe. Trench side slopes should be laid back in steps at a 2:1 slope, minimum.

Maintenance and Safety

Embankment slopes should be no steeper than 3H:1V if possible, with a maximum combined upstream and downstream slope of 5:1 (3:1 downstream face and 2:1 upstream face). For embankments exceeding 15 feet in height, a 6 to 10 foot wide bench should be provided at intervals of 10 to 15 feet of height, particularly if slopes are steeper than 3H:1V.

The following design considerations are provided to help reduce the long-term maintenance burden on the owner(s):

1. *Internal drainage systems in embankments (e.g., drainage blankets, toe drains)* should be designed such that the collection conduits discharge downstream of the embankment at a location where access for observation is possible by maintenance personnel.

2. *Adequate erosion protection* is recommended along the contact point between the face of the embankment and the abutments. Runoff from rainfall concentrates in these areas and may reach erosive velocities depending on the gutter slope and embankment height. Although a sod gutter will be satisfactory for most small embankments, an evaluation should be made to decide if another type of gutter protection is required. For most embankments, a riprap gutter is preferred to a paved concrete gutter.

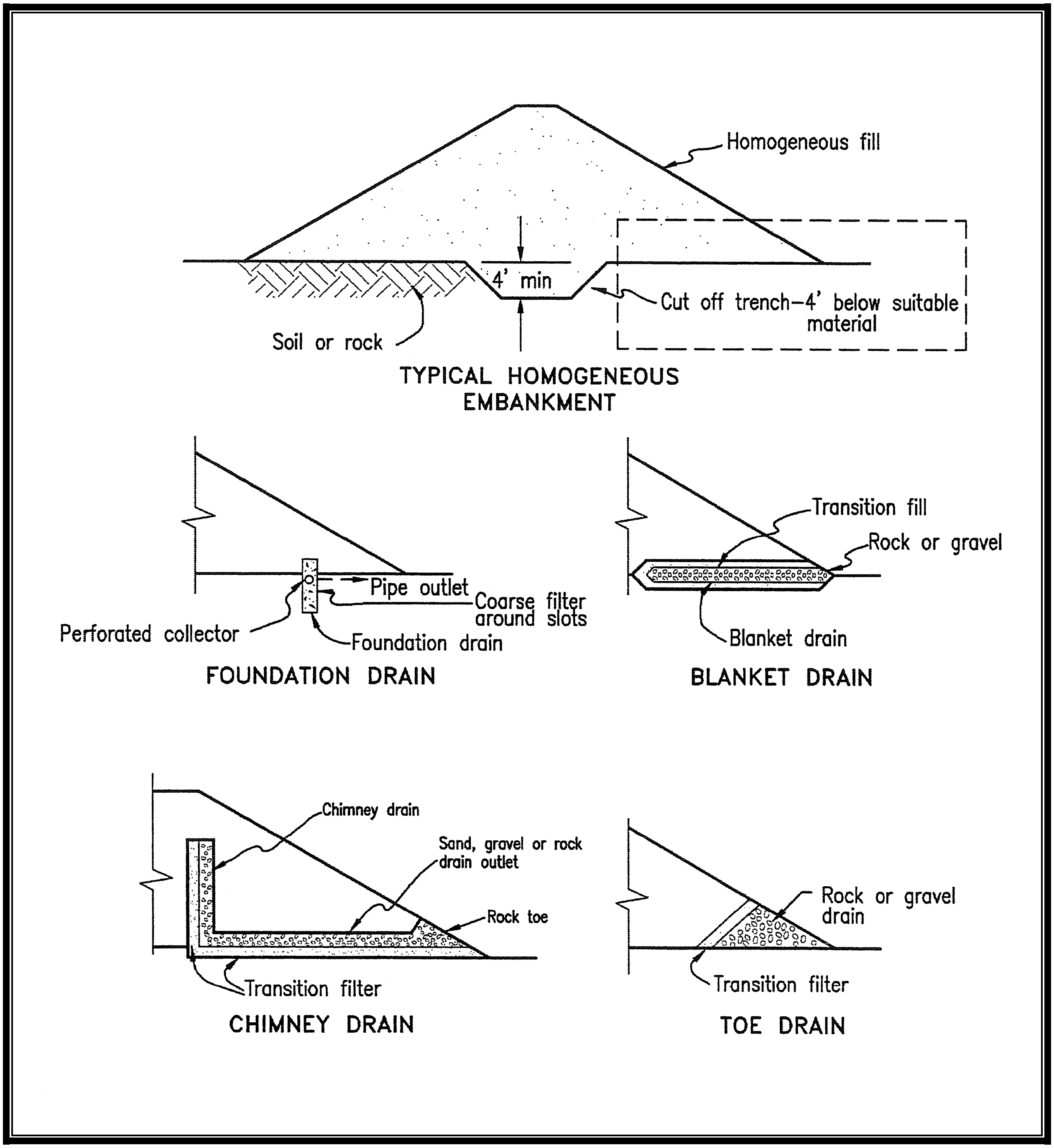
3. *Trees, shrubs, or any other woody plants should not be planted on the embankment* or adjacent areas extending at least 25 feet beyond the embankment toe and abutment contacts.

4. *Access should be provided to all areas of an impoundment that require observation or regular maintenance*. These areas include the embankment, emergency spillway, basin shoreline, principal spillway outlet, stilling basin, toe drains, riser structure, extended-drawdown device, and likely sediment accumulation areas.

SECTION A-8: REGIONAL AND CLIMATE DESIGN VARIATIONS

Not applicable.

SECTION A-9: TYPICAL GRAPHICAL DETAILS



Source: SCS Engineering Field Manual

Figure A-1a. ***Homogeneous Embankments w/ Seepage Controls***

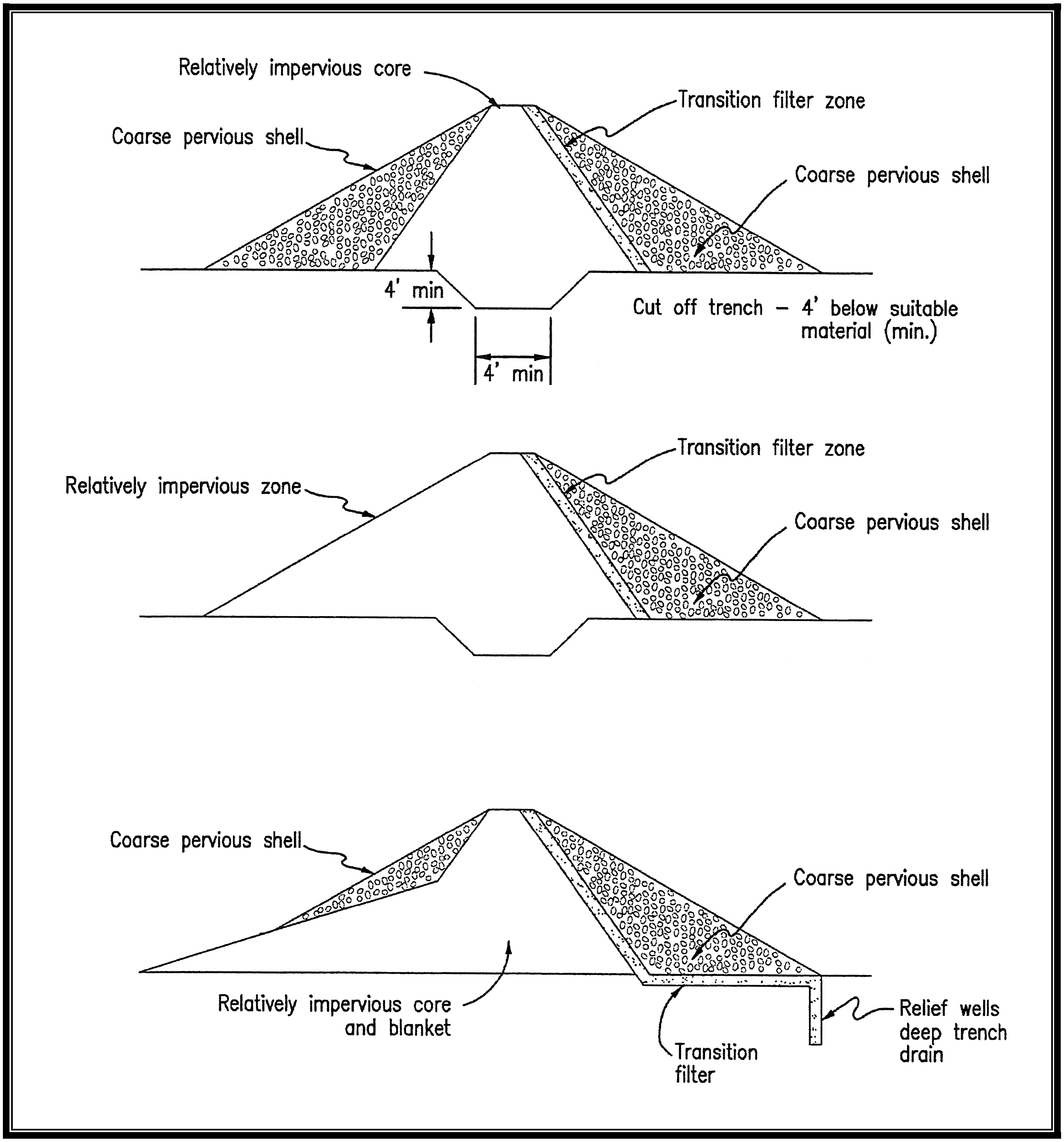


Figure A-1b. Zoned Embankment

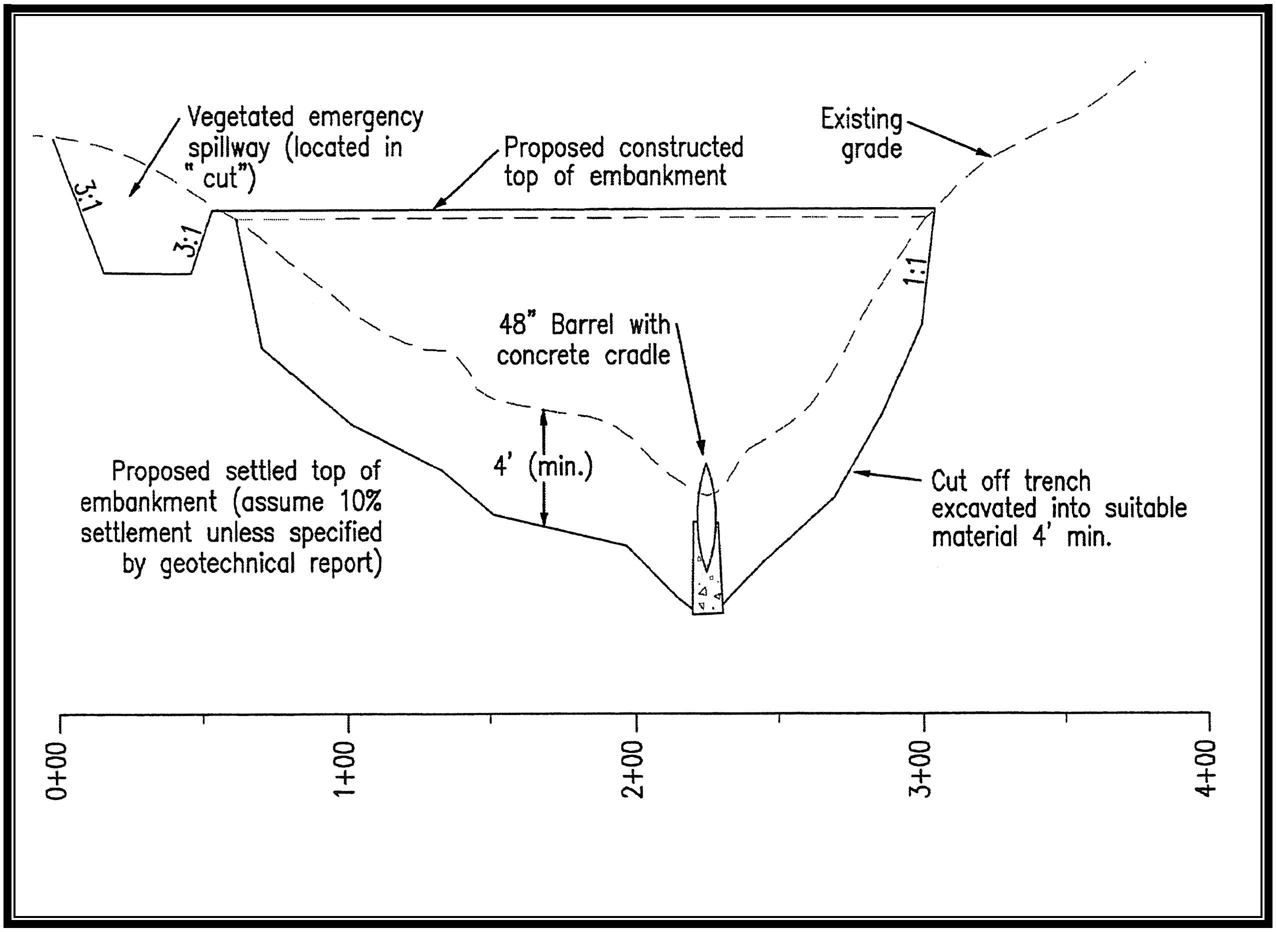


Figure A-2. Profile Along Centerline of Embankment

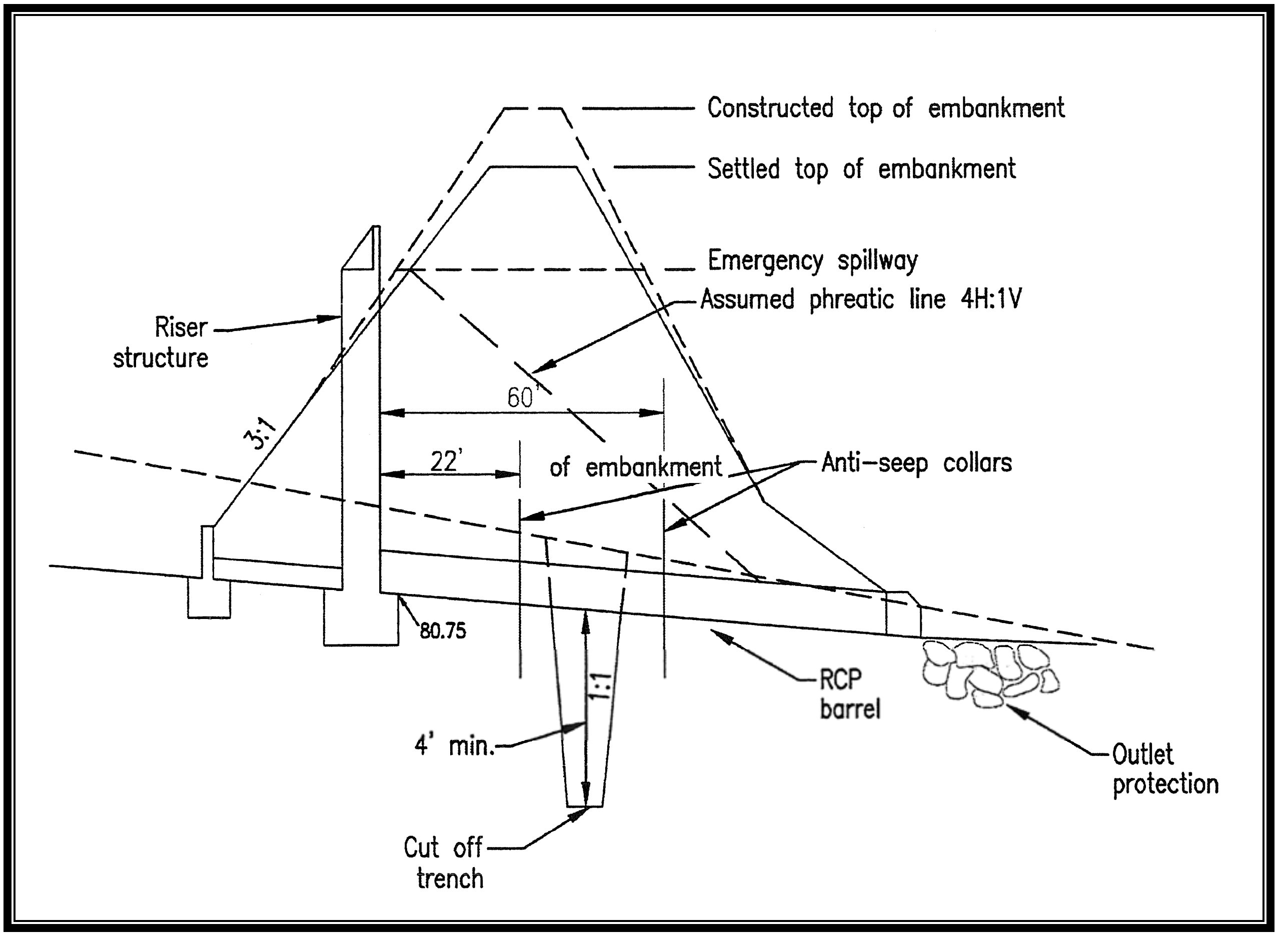


Figure A-3. Profile Along Centerline of Principal Spillway

SECTION A-10: MATERIAL SPECIFICATIONS

Not applicable.

SECTION A-11: CONSTRUCTION SEQUENCE AND INSPECTION

The construction specifications for earthen embankments outlined below should be considered as minimum guidelines, with the understanding that more stringent specifications may be required depending upon individual site conditions, as evaluated by the geotechnical engineer. Final construction specifications should be included on the construction plans. In general, widely accepted construction standards and specifications for embankments, such as those developed by the USDA Soil Conservation Service or the U. S. Army Corps of Engineers, should be followed.

Further guidance can be found in the USDA-NRCS *Engineering Field Manual* and *National Engineering Handbook*. Specifications for the embankment work should conform to the methods and procedures indicated for installing earthwork, concrete, reinforcing steel, pipe, water gates, metal work, woodwork and masonry, as they apply to the site and the purpose of the structure. The specifications should also satisfy all requirements of the local government.

Site Preparation

Areas designated for borrow sites, embankment construction, and structural work should be cleared, grubbed and stripped of topsoil. All trees, vegetation, roots and other objectional material should be removed.

All cleared and grubbed material should be disposed of outside and below the limits of the embankment and reservoir, as directed by the owner or his representative. When specified, a sufficient quantity of topsoil should be stockpiled in a suitable location for use on the embankment and other designated areas.

Earth Fill

1. **Material** - Fill material should be taken from an approved, designated borrow area. It should be free of roots, stumps, wood, rubbish, stones greater than 6 inches, and frozen or other objectionable materials. Fill material for the center of the embankment and the cutoff trench should conform to Unified Soil Classification GC, SC, or CL. Consideration may be given to the use of other materials in the embankment based on the recommendations of a geotechnical engineer supervises the design and construction.

2. **Placement** - Areas on which fill is to be placed should be scarified before its placement. Fill material should be placed in layers a maximum of 8 inches thick (before compaction), which should be continuous over the entire length of the fill. The most permeable borrow material should be placed in the downstream portions of the embankment. The principal spillway must be installed concurrently with fill placement and **not excavated** into the embankment.

3. **Compaction** - Fill material should be compacted with appropriate compaction equipment such as a sheepsfoot, rubber-tired or vibratory roller. The number of required passes by the compaction equipment over the fill material may vary with soil conditions. Fill material should contain sufficient moisture such that the required degree of compaction will be obtained with the equipment used.

   The minimum required density is 95% of maximum dry density with a moisture content within ∀ 2% of the optimum, unless otherwise specified by the engineer. Each layer of the fill should be compacted as necessary to obtain minimum density and the engineer should certify, at the time of construction, that each fill layer meets the minimum density requirement. All compaction is to be determined by either Standard Proctor Test (ASTM D698) or the Modified Proctor Test (ASTM D1557) as directed by the geotechnical engineer based on site and soil conditions and the size and type of structure being built.

4. **Cutoff Trench** - The cutoff trench should be excavated into impervious material along or parallel to the centerline of the embankment as shown on the plans. The equipment used for excavation should govern the bottom width of the trench, with the minimum width being 4 feet. The depth should be at least 4 feet below existing grade or as shown on the plans. The side slopes of the trench should be 1H:1V or flatter. The backfill should be compacted with construction equipment, rollers, or hand tampers to assure maximum density and minimum

permeability.

5. **Top Soil** - The surface layer of compacted fill should be scarified prior to placement of at least 6 inches of topsoil. The topsoil shall be stabilized with in accordance with the Virginia Erosion and Sediment Control Handbook, latest edition.

Figure A-4. Stabilization of a Newly Constructed Earthen Embankment

Structure and Conduit Backfill

Backfill that is beside pipes or structures should be of the same type and quality as specified for the adjoining fill material. The fill should be placed in horizontal layers not to exceed 4 inches in thickness and compacted by hand tampers or other manually directed compaction equipment. The material should completely fill all spaces under and beside the pipe. During the backfilling operation, equipment should not be driven closer than 4 feet, as measured horizontally, to any part of a structure. Also, equipment should **NEVER** be driven over any part of a structure or pipe, unless compacted fill has been placed to a depth specified by the structural live load capacity of the structure or pipe in order to adequately distribute the load.

Filters and Drainage Layers

In order to achieve maximum density of clean sands, filter layers should be flooded with clean water and vibrated just after the water drops below the sand surface. The filter material should be placed in lifts of no more than 12 inches.

Up to four feet of embankment material may be placed over a filter material layer before excavating back down to expose the previous layer. After removing any unsuitable materials, the trench may be filled with additional 12 inch lifts of filter material, flooded, and vibrated as described above, until the top of adjacent fill is reached.

Filter fabrics should not be used in lieu of sands and gravel layers within the embankment.

SECTION A-12: OPERATION AND MAINTENANCE

A thick, healthy grass cover, free of trees and brush, should be maintained on the embankment. Such a cover will help stabilize the surfaces of the embankment and will simplify inspections.

The maintenance and inspection guidelines presented below are **NOT** all-inclusive. Specific facilities may require other measures not discussed here. It is the designer's responsibility to decide if additional measures are necessary.

1. The embankment should be mowed periodically during the growing season, ensuring that the last cutting occurs at the end of the season. The grass should not be cut less than 6 to 8 inches in height.

2. If necessary, the embankment should be limed, fertilized and seeded in the fall, after the growing season. Lime and fertilizer application rates should be based on soil test results. The type of seed should be consistent with that originally specified on the construction plans.

3. All erosion gullies noted during the growing season should be backfilled with topsoil, reseeded and protected (mulched) until vegetation is established.

4. All bare areas and pathways on the embankment should be properly seeded and protected (mulched) or otherwise stabilized to eliminate the potential for erosion.

5. All animal burrows should be backfilled and compacted and burrowing animals should be removed from the area.

6. All trees, woody vegetation and other deep-rooted growth, including stumps and associated root systems, should be removed from the embankment and adjacent areas extending to at least 25 feet beyond the embankment toe and abutment contacts. The root systems should be extracted and the excavated volume replaced and compacted with material similar to the surrounding area. All seedlings should be removed at the first opportunity. Similarly, any vine cover and brush should be removed from the embankment to allow for inspections.

7. Any repairs made to the principal spillway (riser or barrel) should be reviewed by a professional engineer. Vertical trenching to expose the barrel should not be allowed under

any circumstances. The trench side slopes should be stepped back at a 2:1 slope, minimum.

SECTION 13: REFERENCES

ASTM D-2487. *Classification of Soils for Engineering Purposes*.

ASTM D-2488. *Description and Identification of Soils* (visual-manual procedure).

Maryland Department of the Environment-Dam Safety Division. *Dos and Don'ts for Pond Construction*. May 1997.

Sowers, George F. *Introductory Soil Mechanics and Foundations: Geotechnical Engineering*.

Terzaghi and Peck. *Soil Mechanics in Engineering Practice*.

USDA Natural Resource Conservation Service. *Engineering Field Manual*.

USDA Natural Resource Conservation Service. *National Engineering Handbooks*.

USDA Natural Resource Conservation Service, Soil Mechanics Notes:

- SM Note No. 1, Guide for Determining the Gradation of Sand and Gravel Filters.
- SM Note No. 2, Light Weight Piston Sampler for Soft Soils and Loose Sands.
- SM Note No. 3, Soil Mechanics Considerations for Embankment Drains.
- SM Note No. 4, Preparation and Shipment of Undisturbed Core Samples.
- SM Note No. 5, Flow Net Construction and Use.
- SM Note No. 6, Glossary, Symbols, Abbreviations, and Conservation Factors.
- SM Note No. 7, The Mechanics of Seepage Analysis.
- SM Note No. 8, Soil Mechanics Testing Standards.
- SM Note No. 9, Permeability of Selected Clean Sands and Gravels.
- SM Note No. 10, The Static Cone Penatrometer: The Equipment and Using the Data.

USDA Natural Resource Conservation Service, Technical Releases:

- TR 709. *Dimensioning of Filter-Drainage Diaphragms for Conduits According to TR-60*.
- TR 026. *The Use of Soils Containing More Than 5% Rock Larger Than the No.4 Sieve*.
- TR 027. *Laboratory and Field Test Procedures for Control of Density and Moisture of Compacted Earth Embankments.*
- TR 028. *Clay Minerals*.
- TR 071. *Rock Materials Field Classification Procedure*.
- TR 60. *Earth Dams and Reservoirs*

U.S. Department of the Interior. *Design of Small Dams*. 1987.

U.S. Department of the Interior, Bureau of Reclamation. *Guidelines for Controlling Seepage Conduits through Embankments*.

Virginia Erosion and Sediment Control Handbook. Richmond, Virginia: 1992.

APPENDIX B
PRINCIPLE SPILLWAY

VERSION 1.0
March 1, 2011

SECTION B-1: DESCRIPTION OF PRACTICE

A principal spillway is the primary outlet device for a stormwater impoundment. It usually consists of either a *riser structure in combination with an outlet conduit*, which extends through the embankment, or *a weir control section* cut through the embankment. The purpose of a principal spillway is to provide a primary outlet for storm flows, usually up to the 10- or 25-year frequency storm event. The principal spillway is designed and sized to regulate the allowable discharge from the impoundment facility.

SECTION B-2: PERFORMANCE CRITERIA

Not applicable.

SECTION B-3: PRACTICE APPLICATIONS AND FEASIBILITY

A principal spillway is used on any impoundment BMP, including retention, extended-detention, and detention facilities. It may also be used with constructed wetlands and infiltration measures.

SECTION B-4: ENVIRONMENTAL AND COMMUNITY CONSIDERATIONS

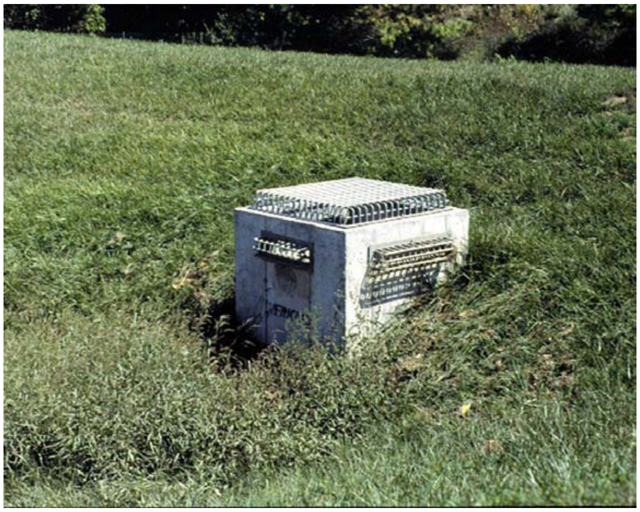
Not applicable.

SECTION B-5: DESIGN APPLICATIONS AND VARIATIONS

A principal spillway typically consists of a *multistage riser structure* and an outlet conduit or a *weir* that allows flow to pass over a *control section* of the embankment. The shape and geometry of the weir as well as that of the riser structure can be manipulated to meet the needs of the specific facility. The use of a weir as the principal spillway eliminates the barrel projecting through the embankment. The barrel through the embankment and the associated piping and seepage control represent not only significant material and construction costs, but also the potential trouble spots for long-term maintenance and possible repair.

The most common type of riser structure is a drop *inlet spillway*. A drop inlet spillway usually consists of a rectangular or other shaped riser structure containing one or several openings sized to control one or more discharge rates. For aesthetic or safety concerns, the drop inlet riser structure may be installed in the embankment with only its top showing. The discharge openings may be extended to the design water surface elevations with pipe. See **Figures B-1(a-f)** for typical riser structures and locations.

The barrel shape or geometry and size through the embankment is based upon the required flow capacities and availability of materials.



Principal Spillway Multi-Stage Riser:
Bird Cage Trash Rack

Principal Spillway Multi-Stage Riser
for a Temporary Sediment Basin

Principal Spillway Multi-Stage Riser
with a V-Shaped Wei

SECTION B-6: SIZING AND TESTING GUIDELINES

Not applicable.

SECTION B-7: DESIGN CRITERIA

The purpose of this section is to provide minimum design recommendations and guidelines for principal spillway systems (riser structure and barrel). The designer is responsible for determining those aspects that are applicable to the particular facility being designed, and for determining if any additional design elements are required to insure the long-term functioning of the system.

One very important requirement is that the crest elevation of the principal spillway must be at least 1.0 ft. below the crest of the emergency spillway.

Drop Inlet Spillways

Drop inlet spillways (riser and barrel system) should be designed such that a) *full flow is established in the outlet conduit and riser at the lowest head over the riser crest as is practical*, and b) *the facility operates without excessive surging, noise, vibration, or vortex action at any stage*. To meet these two requirements, the riser must have a larger cross-sectional area than the outlet conduit. **Chapter 13** of the *Virginia Stormwater Management Handbook* (2009) provides the basic hydraulic calculation procedures needed to design the spillway riser and barrel system.

Headwall/Conduit Spillways

Headwall spillways consist of a pipe extending through an embankment with a headwall at the upstream end. The headwall is typically oversized to provide an adequate surface against which to compact the embankment fill.

Weir Spillways

A weir spillway, when used as a principal spillway, should be armored with concrete or other non-erosive material, since it usually carries water during every storm event. At the spillway, armoring should extend from the upstream face of the embankment to a point downstream of the spillway toe.

In general, all principal spillways should be constructed of a nonerosive material. The selected material should have an anticipated life expectancy similar to that of the stormwater management facility. Precast riser structures cannot be substituted if plans call for a cast in place structure, unless approved by the design engineer and the plan approving authority. Sections of precast structures must be anchored together for stability and flotation requirements. A structural engineer should evaluate shop drawings for pipe, precast structures, or other fabricated appurtenances before fabrication or installation. **Cinder block and masonry block structures should not be used**.

Vegetated spillways designed to carry flow during the 100-year frequency storm or greater are discussed in **Appendix C**, **Vegetated Emergency Spillway**.

Combined Principal and Emergency Spillways

An *emergency spillway*, separated from the principal spillway, is generally recommended. However, using an overland emergency spillway at the embankment abutments may not be practical due to site limitations, such as the following:

- Topographic conditions (e.g., abutments are too steep)
- Land use conditions (e.g., existing or proposed development imposes constraints)
- Other factors (e.g., roadway embankments are used as a dam, basins are excavated, etc.).

In these instances, a *combined principal/emergency spillway* may be considered. A combined principal/emergency spillway is simply a single spillway structure that conveys both low flows and extreme flows (such as the 100-year frequency flow). The combined spillway may take the form of a drop inlet spillway, a weir spillway, a headwall/conduit spillway or any other spillway type.

A primary design consideration for a combined principal/emergency spillway, particularly if it is a drop inlet spillway, is protection against clogging.

<u>Conduits/Structures through Embankments</u>

The *contact point* between the embankment soil, the foundation material, and the conduit is the most likely location for *piping* to occur due to the discontinuity in materials and the difficulty in compacting the soil around the pipe. Therefore, special attention must be given to the design of any conduit that penetrates an embankment.

It is highly recommended that the designer limit the number of conduits that penetrate through an embankment. Whenever possible, utility or other secondary conduits should be located outside of and away from the embankment. When additional conduits cannot be avoided, they should meet the requirements for spillways i.e., water tight joints, no gravel bedding, encasement in concrete or flowable fill, restrained to prevent joint separation due to settlement, etc.

Many embankment failures occur along the principal spillway because of the difficulty in compacting soil along a pipe. To help alleviate this concern, designers should consider the use of a weir as a control structure.

An additional cause of embankment failure is the separation of pipe joints due to differential settlement and pipe deflection. Corrugated metal pipe (CMP) must meet or exceed the minimum required thickness specified in **Table B-1**. The contractor and project inspector should verify the metal thickness (compare manufacturer's certification which accompanies the pipe shipment with the plan specifications), corrugation size, proper connecting bands, and gasket type. Maximum allowable deflection of CMP conduits is 5% of the pipe diameter. However, with larger pipe sizes, it may be difficult to get watertight joints even if the deflection is less than that which is allowed. For increased design life, the engineer may choose to specify a heavier gage than indicated in **Table B-1**.

Watertight joints are necessary to prevent infiltration of embankment soils into the conduit. All joints must be constructed as specified by the pipe manufacturer. "Field joints" where the ends of the pipes are cut off in the field should not be accepted. In addition, six inch hugger bands and "dimple bands" should not be accepted for CMP conduits. The construction specifications (found later in this Standard) specify 12-inch bands with 12-inch O-ring or flat neoprene gaskets for pipes 24 inches or less in diameter. Larger pipes require 24-inch wide bands with 24-inch wide flat gaskets and four "rod and lug" type connectors. Flanged pipe with gaskets is also permitted. Refer to the Construction Specifications in this standard for more information.

All pipe gaskets should be properly lubricated with the material provided by the pipe manufacturer. Use of an incorrect lubricant may cause deterioration of gasket material.

Conduit Piping and Seepage Control – *Seepage* or *piping* along a pipe conduit, which extends through an embankment, should be controlled by use of one of the following: (1) *anti-seep collars*, as shown in **Figure B-2**, or (2) *filter or drainage diaphragms* as shown in **Figure B-3**. Concrete cradles, as discussed in item 3 below, may also be used.

Seepage control will not be required on pipes less than 6 inches in diameter.

1. *Anti-Seep Collars*: These collars lengthen the percolation path along the conduit, subsequently reducing the *exit gradient*, which helps to reduce the potential for piping. While this works well in theory, the required quality of compaction around the collars is very difficult to achieve in the field.

The Bureau of Reclamation, the U.S. Army Corps of Engineers, and the USDA-Natural Resource Conservation Service no longer recommend the use of anti-seep collars. The U.S. Department of the Interior-Bureau of Reclamation issued *Technical Memorandum No. 9* in 1987 that states:

> *"When a conduit is selected for a waterway through an earth or rockfill embankment, cutoff collars will not be selected as the seepage control measure."*

Alternative measures have been developed and used in the designs of major structures. These measures include *graded filters* or *filter diaphragms*, and *drainage blankets*. These devices are not only less complicated and more cost-effective to construct than the cutoff collars, but also allow for easier placement of the embankment fill.

Designers and engineers, however, continue to use anti-seep collars as the sole method of seepage control for small dams. This may be due to the complexity of the design procedure for graded filters. It may also be due to the designer's concern that little engineering supervision and/or inspection will occur during construction, which is generally necessary for the successful installation of graded filters.

Anti-seep collars, when used, should be installed around all conduits through earth fills according to the following criteria:

a. Enough collars should be placed to increase the seepage length along the conduit by a minimum of 15%. This percentage is based on the length of pipe in the saturation zone.

b. The assumed normal saturation zone should be determined by projecting a line through the embankment, with a 4H:1V slope, from the point where the normal water elevation meets the upstream slope to a point where it intersects the invert of the conduit. This line, referred to as the *phreatic line*, represents the upper surface of the zone of saturation within the embankment. For stormwater management basins, the phreatic line starting elevation should be the 10-year storm pool elevation. (See **Appendix A**, **Earthen Embankment**.)

c. Maximum collar spacing should be 14 times the minimum projection above the pipe. The minimum collar spacing should be 5 times the minimum projection.

d. Anti-seep collars should be placed within the saturation zone. In cases where the spacing limit will not allow this, at least one collar should be in the saturation zone.

e. All anti-seep collars and their connections to the conduit should be watertight and made of material compatible with the conduit.

f. Collar dimensions should extend a minimum of 2 feet in all directions around the pipe.

g. Anti-seep collars should be placed a minimum of 2 feet from pipe joints unless flanged joints are used.

The calculation procedure for sizing anti-seep collars is presented in **Chapter 13** of the *Virginia Stormwater Management Handbook* (2009): Multi-Stage Riser Design, STEP 15.

2. *Filter and Drainage Diaphragms*: Anti-seep collars extend the flow path along the conduit and, therefore, discourage piping. In contrast, filter and drainage diaphragms do not eliminate or discourage piping, rather they control the transport of embankment fines, which is the major concern in piping and seepage. Rather than trying to prevent seepage or increase its flow length, these devices channel the flow through a filter of fine graded material, such as sand, which traps any embankment material being transported. The flow is then conveyed out of the embankment through a perforated toe drain or other acceptable technique.

While filter and drainage diaphragms require careful design, the procedure is straightforward. The *grain size distribution* of the embankment fill and foundation material must be determined so that the filter material grain size distribution can be specified. If the specified filter material is not available on the site, it must be imported. The design procedure for filter and drainage diaphragms can be found in the following references:

- USDA-NRCS *TR-60*
- USDA-NRCS *Technical Note No. 709*
- USDA-NRCS *Soil Mechanics Notes 1 and 3* (Available upon request from DEQ or NRCS)

There are some distinct advantages to using filter diaphragms over anti-seep collars:

- By eliminating the obstructions created by anti-seep collars, heavy compaction equipment can more thoroughly compact the embankment fill material adjacent to the conduit.

- The labor intensive formwork associated with anti-seep collar construction is eliminated.

- Cracks that form in the fill along the conduit will be terminated by the filter and will not propogate completely through the dam.

A geotechnical engineer should supervise the design of filter and drainage diaphragms. The critical design element is the grain size distribution of the filter material compared with that of the embankment fill and foundation material.

Overall, the following criteria apply to the use of filter and drainage diaphragms:

a. The diaphragm should consist of sand, meeting fine concrete aggregate requirements (at least 15% passing the No. 40 sieve but no more than 10% passing the No. 100 sieve). If unusual soil conditions exist, a special analysis should be completed.

b. The diaphragm should be a minimum of 3 feet thick and should extend vertically **upward** and **horizontally** at least 3 times the pipe diameter and vertically **downward** at least 24 inches beneath the barrel invert, or to rock, whichever is encountered first (SCS Tech. Note 709).

c. The diaphragm should be placed immediately downstream of the cutoff trench, approximately parallel to the centerline of the dam.

d. In order to achieve maximum density of clean sands, filter layers should be flooded with clean water and vibrated just after the water drops below the sand surface. The filter material should be placed in lifts of no more than 12 inches.

   Up to four feet of embankment material may be placed over a filter material layer before excavating back down to expose the previous layer. After removing any unsuitable materials, the trench may be filled with additional 12-inch lifts of filter material, flooded and vibrated as described above, until the top of adjacent fill is reached.

e. The diaphragm should be discharged at the downstream toe of the embankment. The opening sizes for slotted and perforated pipes in drains must be designed using the filter criteria. A second filter layer may be required around the drain pipe in order to alleviate the need for many very small openings. Fabric should ***not*** be used around the perforated pipe as it may clog rendering the perforations impenetrable by water.

The construction specifications for a filter diaphragm should include provisions to prevent settlement of the filter material upon saturation. This is usually accomplished by flooding the filter upon installation and compacting with vibratory equipment as soon as the water drops below the surface (Van Aller, 1990).

Whatever measures are taken to control seepage, proper construction techniques and inspection are critical to a successful project. The contractor should ensure that backfill material meets the specifications for *quality*, *lift thickness*, *placement*, *moisture content*, and *dry unit weight*. In addition, special care should be taken in the placement and compaction of the embankment material beside the barrel. Compaction along this conduit must extend away from the pipe enough to overlap with the compaction of the embankment. The use of filter and drainage diaphragms will ease this effort while providing greater protection against the damaging effects of piping and seepage.

During construction, it is recommended that a qualified professional inspect filter and drainage diaphragms. Inspection logs should be submitted along with any as-built plans.

3. *Concrete Pipe Bedding*: If the embankment fill material under the spring line of the conduit is **inadequately** compacted, *piping* may result. This problem is magnified if the conduit is not designed with flexible watertight joints; differential settlement of the embankment and foundation materials may pull the conduit joints apart, allowing the stormwater to escape into the surrounding soil, greatly adding to the piping condition. Installation of a concrete cradle will help to reduce the risk of piping under the barrel and the subsequent failure of the embankment, resulting from differential settlement.

Cradles not only provide conduit support, but also provide a better condition for the placement and compaction of backfill.

Concrete cradles serve two distinctly different, yet related functions: 1)they help to prevent piping along conduit, and 2) they provide a 90° bedding angle for the loading support of the conduit.. See Figure B-4.

The concrete cradle may not be necessary along the entire length of the conduit to prevent piping, but it is recommended. This will eliminate a sudden change in the support provided under the conduit. The load distribution of the conduit is assumed to be the same as the typical load distribution characteristics of reinforced concrete pipe (*RCP*). The external loading capacity of *RCP* depends upon a bedding condition that provides equal support around the base of the pipe. General pipe culvert installation specifications call for the placement of gravel under the pipe to distribute the load evenly. However, g**ravel bedding under an embankment conduit is *never* appropriate unless it is designed as a filter or drainage diaphragm.** Therefore, if the external load on the barrel is enough to warrant provision for its maximum ***supporting strength***, then a concrete cradle should be installed along the conduit's entire length. Note that external loads on the barrel may be due to the height of the embankment fill, the anticipated construction traffic, or the weight of the compaction equipment.

Single Conduits: All conduits penetrating dam embankments should be designed using the following criteria:

a. Conduits and structures penetrating an embankment should have a smooth surface without protrusions or indentations that will hinder compaction of embankment materials.

b. All conduits should be circular in cross-section except cast-in-place reinforced concrete box culverts.

c. Conduits should be designed to withstand the external loading from the proposed embankment without yielding, buckling or cracking, all of which will result in joint separation.

d. Conduit strength should not be less than the values shown in **Tables B-1** and **B-2** for corrugated steel, aluminum, and PVC pipes, and the applicable ASTM standards for other materials. The manufacturer should submit certification that the pipe meets plan requirements for design load, pipe thickness, joint design, etc.

e. Inlet and outlet flared-end sections should be made from materials that are compatible with the pipe.

f. All pipe joints should be made watertight by using flanges with gaskets, coupling bands with gaskets, bell and spigot ends with gaskets, or by welding. See **Section B-11, Construction Specifications and Inspections** later in this Appendix.

Multiple Conduits: Where multiple conduits are used, each conduit should conform to the requirements in item (b), above. In addition, sufficient space between the conduits and the installed anti-seep collars should be provided to allow for backfill material to be placed between the conduits with earth moving equipment and to allow for easy access by hand-operated compaction equipment. The distance between conduits should be equal to or greater than one-half of the pipe diameter, but not less than 2 feet.

Cathodic Protection

In some areas of Virginia, sedimentary layers may be very acidic. This is particularly common in the coastal and piedmont regions east of the fall line, or roughly east of Interstate 95. Cathodic protection should be provided for *coated welded steel* and *galvanized corrugated metal* pipe when soil and resistivity studies indicate the need for a protective coating. Cathodic protection may also be provided when additional protection and longevity are warranted.

Outlet Protection

Outlet protection should be used on the downstream toe of a spillway structure to help dissipate the high-energy flow through the spillway and to prevent excessive erosion in the receiving channel. Various types of outlet protection can be used including: *riprap at the endwall or end-section of an outlet conduit* or a *designed hydraulic jump with impact blocks*. The type of outlet protection depends on the flow velocities associated with the spillway design flood and energy dissipation required. Riprap is the preferred form of outlet protection when designed according to **Chapter 13** of the *Virginia Stormwater Management Handbook* (2009) and the *Virginia Erosion and Sediment Control Handbook* (VESCH, 1992). Gabion baskets are also an acceptable outlet protection material. Other references for designing outlet protection include publications by the Federal Highway Administration, the USDA-Natural Resource Conservation Service, the U.S. Department of the Interior-Bureau of Reclamation and the U.S. Army Corps of Engineers.

The following general criteria are recommended for the placement of riprap at the outfall of a stormwater impoundment:

1. The bottom of the riprap apron should be constructed at 0% slope along its length. The end of the apron should match the grade and alignment of the receiving channel.

2. If the receiving channel is well defined, the riprap should be placed on the channel bottom and side slopes (no steeper than 2:1) for the entire length, L_a, required per **Chapter 13** of the *Virginia Stormwater Management Handbook* (2009) and the *Virginia Erosion and Sediment Control Handbook* (VESCH, 1992). Riprap placement should not alter the channel's geometry. Excavation of the channel bed and banks may be required to construct the full thickness of the apron.

3. If the barrel discharges into the receiving channel at an angle, the opposite bank must be protected up to the 10-year storm elevation. In no instance should the total length of outlet protection be shortened. If a permit requires that no work may be performed in the stream or channel, then the outlet structure should be moved back to allow for adequate protection.

4. The horizontal alignment of the apron should have no bends within the design length; La. Additional riprap should be placed if a significant change in grade occurs at the downstream end of the outfall apron.

5. Filter fabric should be placed between the riprap and the underlying soil to prevent soil movement into and through the riprap.

<u>Trash Racks and Debris Control Devices</u>

Most basins will collect a certain amount of trash and debris from incoming flows. Floating debris such as grass clippings, tree limbs, leaves, trash, construction debris, and sediment bed load from upstream watersheds are common. Therefore, all control structures, including detention; extended-detention and retention basin low-flow weirs and orifices should have a trash rack or debris control device. The following are recommended design criteria for trash racks and debris control devices:

1. Openings for trash racks should be no larger than one-half of the minimum conduit dimension, and to discourage child access, bar spacing should be no greater than 1 foot apart. The clear distance between the bars on large storm discharge openings should generally be no less than 6 inches.

2. **Flat grates for trash racks are not acceptable**. Inlet structures that have flow over the top should have a non-clogging trash rack such as a hood-type inlet that allows passage of water from underneath the trash rack into the riser, or a vertical or sloped grate. The designer should verify that the surface area of the vertical perimeter of a raised grate equals the area of the horizontal top opening. This will allow adequate flow passage should the top horizontal surface become clogged. Examples are shown in **Figure B-5**.

3. Metal trash racks and monitoring hardware should be constructed of galvanized or stainless steel metal.

4. Methods to prevent clogging of extended detention orifices in dry extended detention basins should be carefully designed since these orifices are usually very small and located at the invert or bottom of the basin (refer to **Design Specification No. 15, Extended Detention**).

Anti-vortex Device

All drop inlet spillways designed for pressure flow should have adequate anti-vortex devices. An anti-vortex device is not required if weir control is maintained in the riser through all flow stages, including the maximum design storm or safety storm.

An anti-vortex device may be a baffle or plate installed on top of the riser, or a headwall set on one side of the riser. Examples of anti-vortex devices are shown in **Figure B-6**.

Drain Pipes and Valves

Stormwater management facilities having permanent impoundments may be designed so that the permanent pool can be drained to simplify maintenance and sediment removal. The draining mechanism will usually consist of a valve or gate attached to the spillway structure and an inlet pipe projecting into the reservoir area with a trash rack or debris control device. The typical configuration of a drainpipe will place the valve inside the riser structure with the pipe extending out to the pool area. This configuration results in the drainpipe being pressurized by the hydraulic head associated with the permanent pool. Pressurized drainpipes should consist of mechanical joints in order to avoid possible leaks and seepage resulting from this condition. In all cases, valves should be secured to prevent unauthorized draining of the facility.

Basin drains should be designed with sufficient capacity to pass the 1-year frequency design storm with limited ponding in the reservoir area, such that sediment removal or other maintenance functions are not hampered.

An uncontrolled or rapid drawdown of a stormwater basin could cause a slide in the saturated upstream slope of the dam embankment or shoreline area. Therefore, the design of a basin drain system should include specific operating instructions for the owner. **Generally, drawdown rates should not exceed 6 inches per day**. For embankments or shoreline slopes of clay or silt, drawdown rates as low as *1 inch per week* may be required to ensure slope stability. (FPFM, 1994).

Antiflotation

The design of a principal spillway riser structure should include a *flotation* or *buoyancy* calculation.

When the ground around the riser is saturated and the water surface elevation in the basin is higher than the riser footing, then the riser structure behaves like a “vessel” floating in water. Such flotation forces on the riser can lead to failure of the connection between the riser and barrel, and any other rigid connections.

The downward force of the riser and footing (assuming the riser is attached firmly to the footing) is the *structure weight.* To maintain adequate stability, this weight must be at least 1.25 times greater than the upward force, or buoyant force, acting on the riser.

An *anti-flotation* calculation procedure is presented in Chapter 13 of the Virginia Stormwater Management Handbook (2009).

Maintenance and Safety

As mentioned previously, trash racks and debris control structures should be sized to prevent entry by children. Fencing or other barriers should be considered around spillway structures having open or accessible drops more than 3 feet. A locking manhole cover on the riser may also be prudent to prevent unauthorized access.

SECTION B-8: REGIONAL AND CLIMATE DESIGN VARIATIONS

Not applicable.

SECTION B-9: TYPICAL GRAPHICAL DETAILS

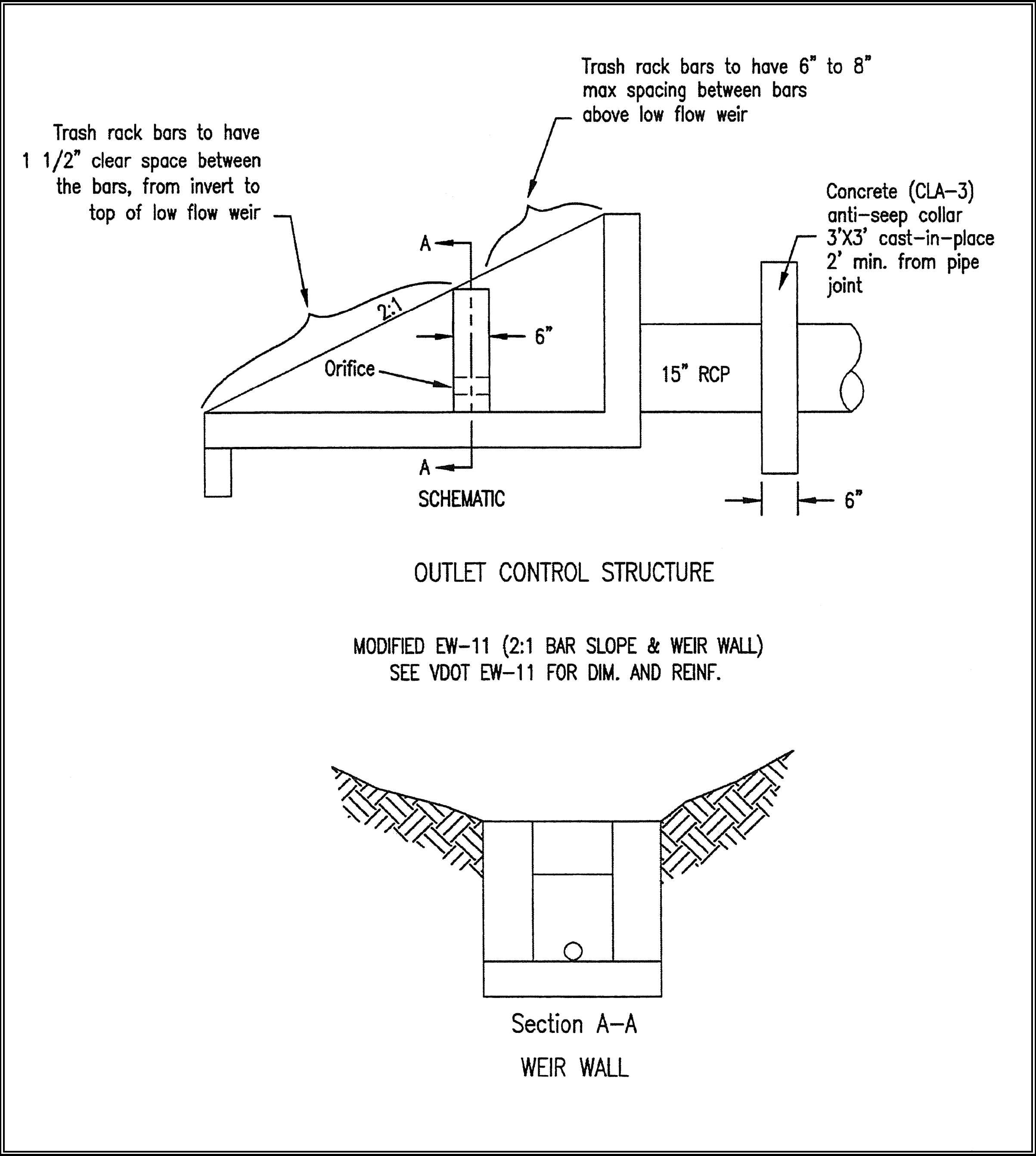


Figure B-1a. Typical Principal Spillway Structures

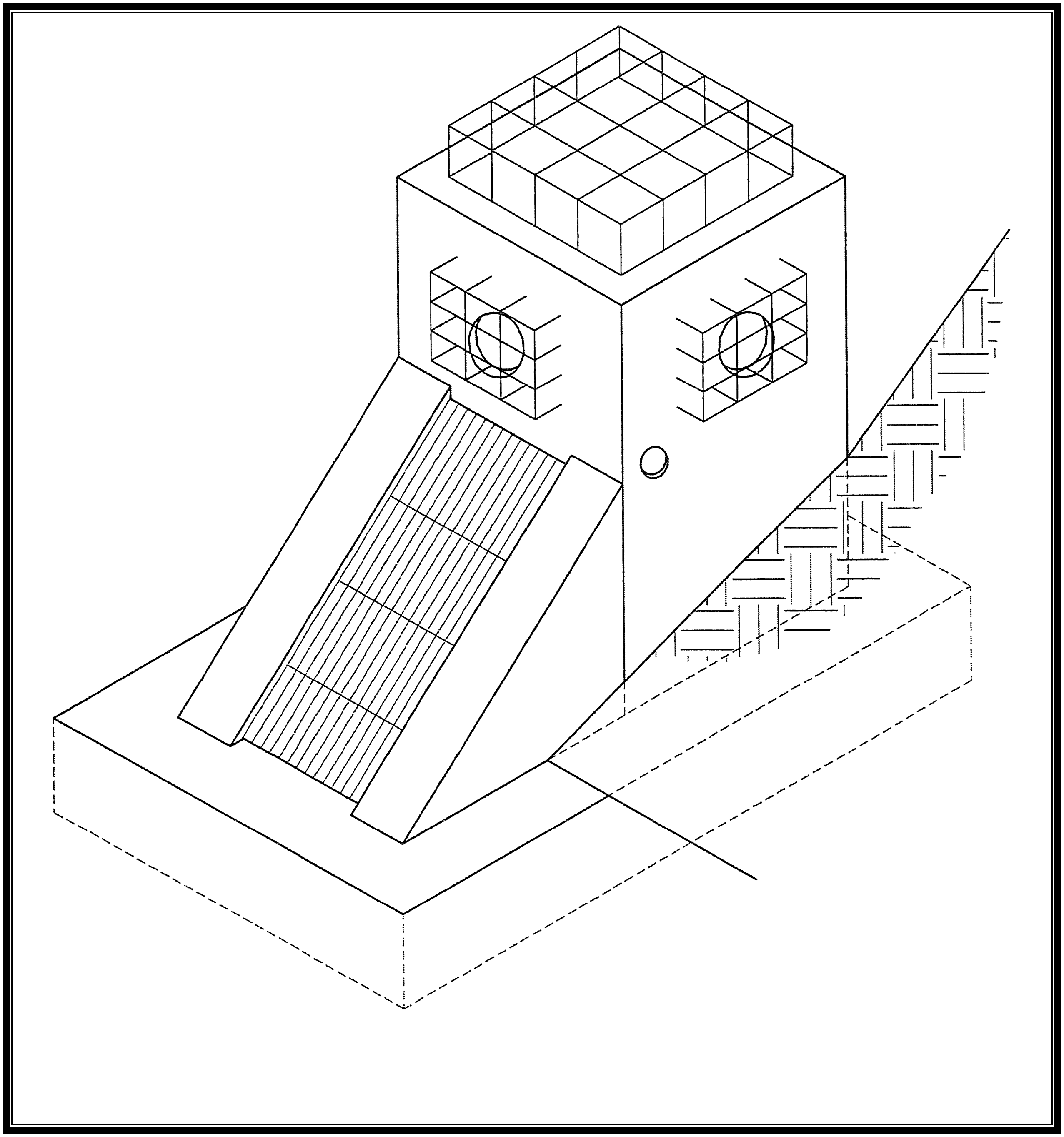


Figure B – 1b. Typical Principal Spillway Structures

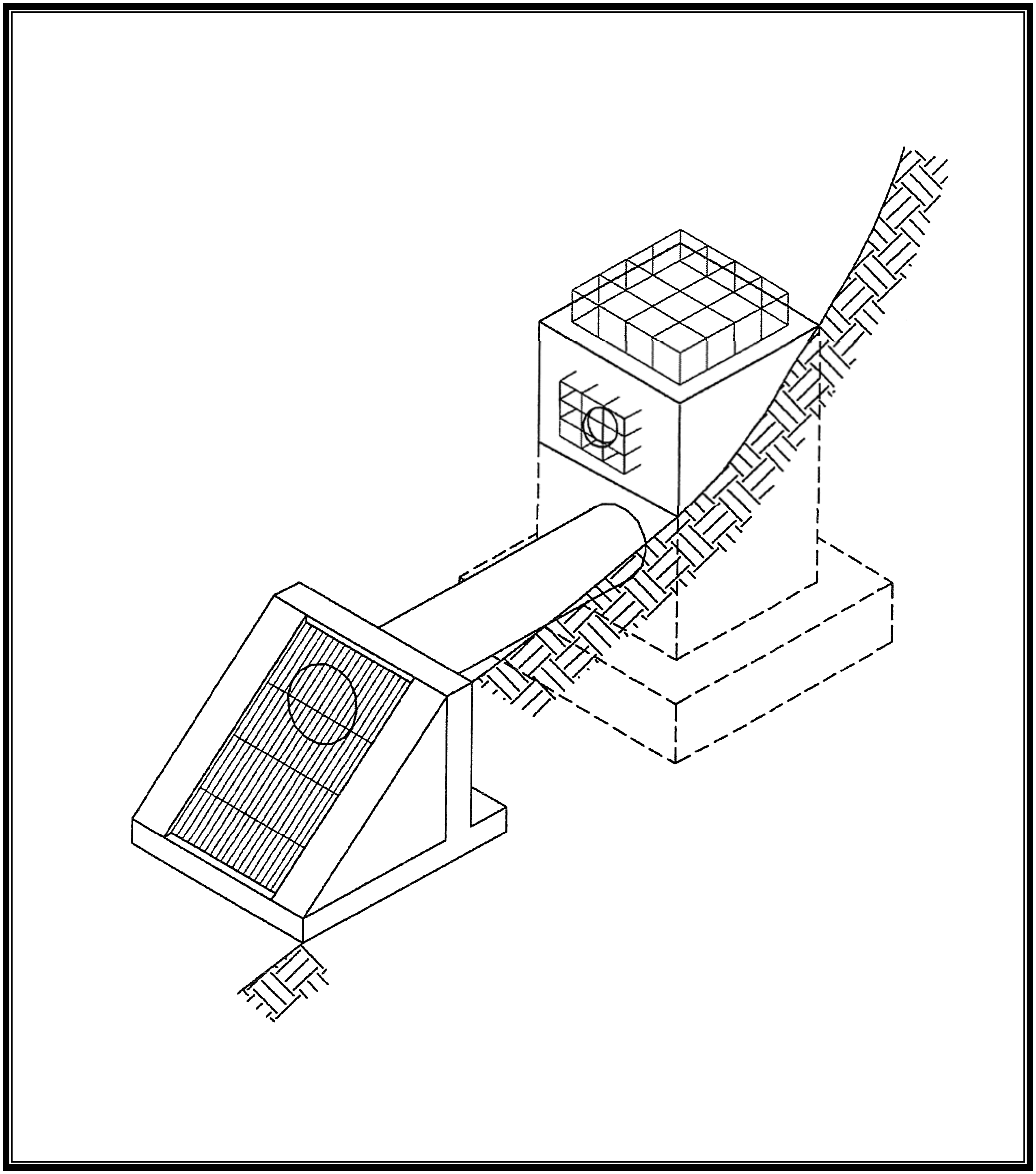


Figure B-1c. Typical Principal Spillway Structures

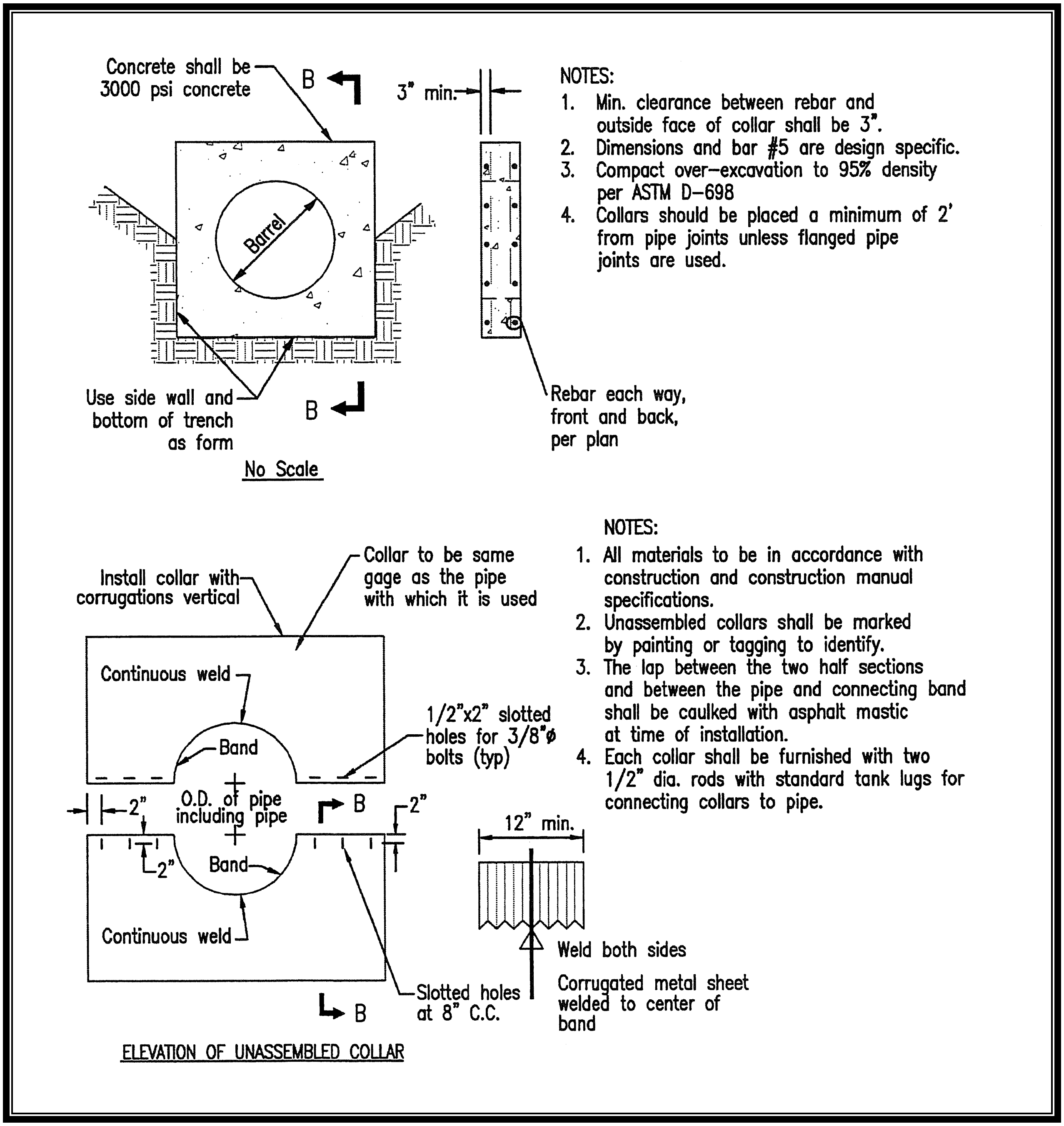
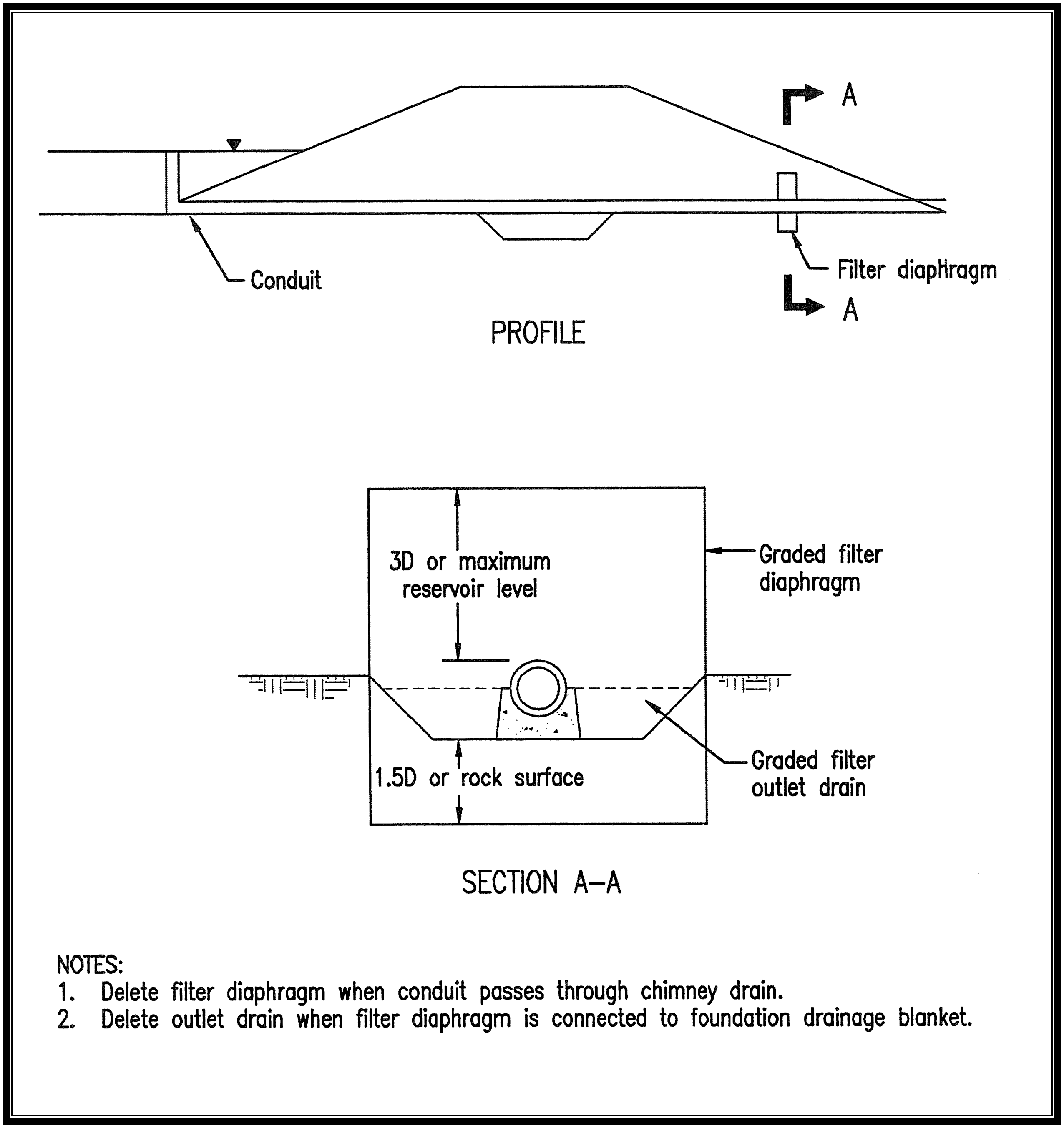


Figure B-2. Concrete Anti-Seep Collar



Source: Seepage Control Along Conduits Penetrating Embankment Dams, Ray E. Martin, Ph.D., P.E.

Figure B-3. Graded Filter Diaphragm for Seepage Control Around Conduit

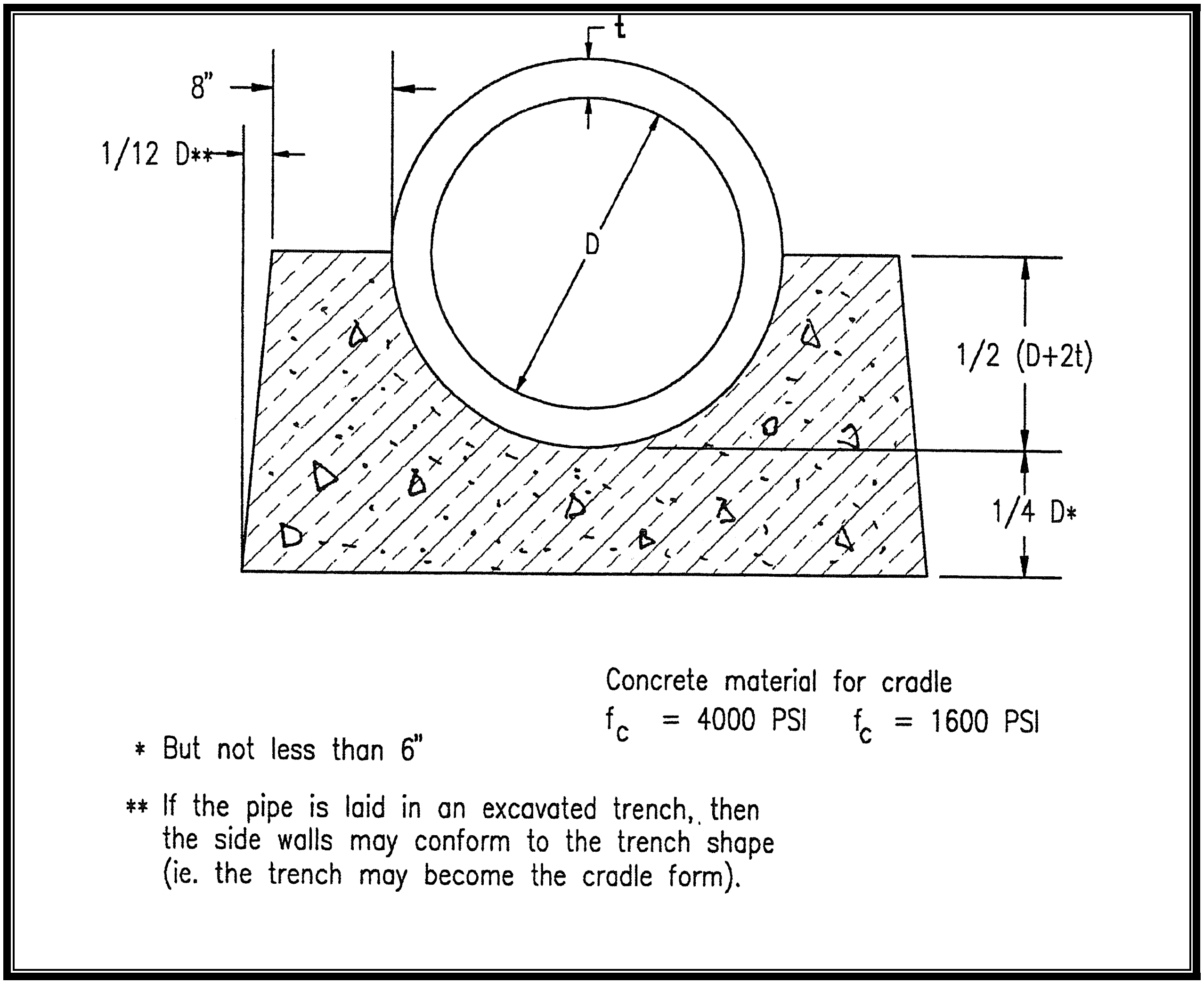


Figure B-4. Concrete Cradle

SECTION B-10: MATERIAL SPECIFICATIONS

Not applicable.

SECTION B-11: CONSTRUCTION SEQUENCE AND INSPECTION

The construction specifications for principal spillways outlined below should be considered as minimum guidelines. More stringent requirements may be needed depending upon individual site conditions. Overall, widely accepted construction standards and specifications, such as those developed by the USDA Natural Resource Conservation Service or the U.S. Army Corps of Engineers, should be followed.

Further guidance can be found in the USDA-NRCS *Engineering Field Manual*. Specifications for the work should conform to the methods and procedures specified for installing earthwork, concrete, reinforcing steel, pipe water gates, metal work, woodwork, and masonry, as they apply to the site and the purpose of the structure. The specifications should also satisfy all requirements of the local government. Final construction specifications should be included on the construction plans.

Corrugated Metal Pipe

The following criteria apply:

1. **Materials:** Corrugated metal pipe may be steel, aluminum coated steel or aluminum.

   a. *Steel Pipe*: This pipe and its appurtenances should be galvanized and fully bituminous coated and should conform to the requirements of AASHTO Specification M-190 Type A with watertight coupling bands. Any bituminous coating damaged or otherwise removed should be replaced with cold applied bituminous coating compound. Steel pipes with polymeric coatings should have a minimum coating thickness of 0.01 inches (10 *mils*) on both sides of the pipe. The following coatings or an approved equal may be used: Nexon, Plasti-Cote, Blac-Clad, and Beth-Cu-Loy. Coated corrugated steel pipe should meet the requirements of AASHTO M-245 and M-246.

   b. *Aluminum Coated Steel Pipe*: This pipe and its appurtenances should conform to the requirements of AASHTO Specification M-274 with watertight coupling bands or flanges. Any aluminum coating damaged or otherwise removed should be replaced with cold applied bituminous coating compound.

   c. *Aluminum Pipe*: This pipe and its appurtenances should conform to the requirements of AASHTO Specification M-196 or M-211 with watertight coupling bands or flanges. Aluminum surfaces that are to be in contact with concrete should be painted with one coat of zinc chromate primer. Hot dipped galvanized bolts may be used for connections. The pH of the surrounding soils should be between 4 and 9.

2. **Coupling bands, anti-seep collars, end-sections, etc.:** All connectors must be composed of the same material as the pipe. Metals must be shielded from dissimilar materials with rubber or plastic insulation at least 24 mils thick.

3. **Connections:** All connections to pipes must be completely watertight. The drain-pipe (or barrel) connection to the riser should be welded all around when both are metal. Anti-seep collars should be connected to the pipe so that they are completely watertight. **Dimple bands are not considered watertight**.

   A rubber or neoprene gasket should be used when joining pipe sections. The end of each pipe should be re-rolled by enough corrugations to fit the bandwidth. The following connection types are acceptable for pipes less than 24 inches in diameter: flanges with gaskets on both ends of the pipe, a 12-inch wide standard lap type band with a 12-inch wide by ½-inch thick closed cell circular neoprene gaskets, and a 12-inch wide hugger type band with 0-ring gaskets having a minimum diameter of 3/8 inches greater than the corrugation depth. Pipes 24 inches in diameter and larger should be connected by a 24-inch long annular corrugated band using rods and lugs and a 24 inch wide by 3/8 inch thick closed cell circular neoprene gasket. Helically corrugated pipe should have either continuous welded seams or lock seams with internal caulking or a neoprene bead.

All pipe gaskets must be properly lubricated with the material provided by the pipe manufacturer, and tensioned. Flat gaskets must be factory welded or solvent glued into a circular ring, with no overlaps or gaps.

4. **Bedding:** The pipe should be firmly and uniformly bedded throughout its length. Where rock or soft, spongy or other unstable soil is encountered, it should be removed and replaced with suitable earth that is subsequently compacted to provide adequate support. Under no conditions should gravel bedding be placed under a conduit through the embankment.

5. **Backfill:** All backfill material and placement should conform to Structure Backfill specifications in **Appendix A, Earthen Embankment**.

Reinforced Concrete Pipe

The following criteria apply:

1. **Materials:** Reinforced concrete pipe should have bell and singular spigot joints with rubber gaskets and should equal or exceed ASTM Designation C-361.

2. **Bedding:** All reinforced concrete pipe conduits should be laid in a **concrete** bedding for their entire length. This bedding should consist of high slump concrete placed under the pipe and up the sides of the pipe at least 25% of its outside diameter, and preferably to the spring line, with a minimum thickness of 3 inches, or as shown on the drawings.

3. **Laying pipe:** Bell and spigot pipe should be placed with the bell end upstream. Joints should be made per recommendations from the manufacturer. After the joints are sealed for the entire run of pipe, the bedding should be placed so that all spaces under the pipe are filled. Care should be taken to prevent any deviation from the original line and grade of the pipe.

4. **Backfill:** All backfill material and placement should conform to Structure Backfill specifications in **Appendix A, Earthen Embankment**.

Polyvinyl Chloride (PVC) Pipe

The following criteria apply:

1. **Materials:** PVC pipe should be PVC-1120 or PVC-1220 conforming to ASTM D-1785 or ASTM D-2241.

2. **Connections:** Joints and connections to anti-seep collars should be completely watertight.

3. **Bedding:** The pipe should be firmly and uniformly bedded throughout its length. Where rock or soft, spongy or other unstable soil is encountered, it should be removed and replaced with suitable earth that is subsequently compacted to provide adequate support.

4. **Backfill:** All backfill material and placement should conform to Structure Backfill specifications in **Appendix A, Earthen Embankment**.

Filters and Drainage Layers

In order to achieve maximum density of clean sands, filter layers should be flooded with clean water and vibrated just after the water drops below the sand surface. The filter material should be placed in lifts of no more than 12 inches.

Up to four feet of embankment material may placed over a filter material layer before excavating back down to expose the previous layer. After removing any unsuitable materials, the trench may be filled with additional 12-inch lifts of filter material, flooded, and vibrated as described above, until the top of adjacent fill is reached.

Filter fabrics should not be used in lieu of sands and gravel layers within the embankment.

Table B-1. Minimum Gages for Metal Pipes

CORRUGATED STEEL PIPE 2-2/3" x ½" Corrugations [1]							CORRUGATED ALUMINUM PIPE 2-2/3" x ½" Corrugations [1]				
Fill Height Over Pipe (ft.)	Pipe Diameter (inches)						Fill Height Over Pipe (ft.)	Pipe Diameter (inches)			
	≤21	24	30	36	42	48		≤21	24	30	36
1 – 15	16	16	16	14	12	10	1 – 15	16	16	14	14
16 – 20	16	16	16	14	12	10	16 – 20	16	14	12	12
21 – 25	16	16	14	12	10	10	21 – 25	16	12	10	*
CORRUGATED STEEL PIPE 3" x 1" or 5" x 1" Corrugations							**CORRUGATED ALUMINUM PIPE [2] 3" x 1" or 5" x 1" Corrugations**				
Fill Height Over Pipe (ft.)	**Pipe Diameter (inches)**						**Fill Height Over Pipe (ft.)**	**Pipe Diameter (inches)**			
	≤24	**30**	**36**	**42**	**48**	**–**		**30**	**36**	**42**	**48**
0 – 20	16	16	16	16	16	–	1 – 15	16	16	16	16
20 – 25	16	16	16	16	14	–	16 – 20	16	14	8	8

[1] Pipe with 6, 8 and 10 inch diameters has 1-1/2 in. x 1/4 in. corrugations
[2] Riveted or helical fabrication
* Not permitted
NOTE: Coatings for corrugated steel should be as specified in this specification, or equivalent

* Not permitted

Source: USDA-NRCS Standards and Specifications for Ponds – Code 378

Table B-2. Acceptable PVC Pipe for Use in Earthen Dams[1]

Nominal Pipe Size (inches)	Schedule or Standard Dimension Ratio (SDR)	Maximum Depth of Fill Over Pipe (feet)
≤ 4	Schedule 40	15
	Schedule 80	20
	SDR 26	10
6, 8, 10, 12	Schedule 40	10
	Schedule 80	15
	SDR 26	10

[1] Polyvinyl chloride pipe, PVC 1120 or PVC 1220, conforming to ASTM D-1785 or ASTM D-2241

Source: USDA-NRCS Standards and Specifications for Ponds – Code 378

Concrete

Concrete should meet the requirements of the Virginia Department of Transportation (VDOT) *Road and Bridge Specifications*, latest edition.

Outlet Protection

Outlet protection should meet the requirements and construction specifications of the VESCH, 1992 edition, Std. & Spec. 3.18, Outlet Protection, and 3.19, Riprap, latest edition. Materials should conform to the following:

1. Filter fabric should meet or exceed the requirements in Standard & Specification 3.18 and 3.19 in the VESCH, 1992 edition.

2. Riprap should meet or exceed the requirements in Standard & Specification 3.18 and 3.19 in the VESCH, 1992 edition.

3. Gabion baskets should be made of hexagonal triple-twist mesh, PVC coated, heavily galvanized steel wire. The maximum linear dimension of the mesh opening should not exceed 4 1/2 inches and the area of the mesh opening should not exceed 10 square inches.

   Stone or riprap for the baskets should be sized according to the following criteria:

Table B-3. Gabion Basket Criteria

BASKET THICKNESS		STONE SIZE
(inches)	(millimeters)	(i)nches
6	150	3 - 5
9	225	4 - 7
12	300	4 - 7
18	460	4 - 7
36	910	4 - 12

   The stone or riprap should consist of fieldstone or rough, unhewn quarry stone. The stone should be hard and angular and of a quality that will not disintegrate from exposure to water or weather. The specific gravity of the individual stones should be at least 2.5.

   Recycled concrete may be used and will be considered equivalent if it has a density of at least 150 pounds per cubic foot and no exposed steel or reinforcing bars.

Trash Rack and Debris Control Devices

All trash rack and debris control components should be stainless steel or galvanized metal per the Virginia Department of Transportation (VDOT) specifications. Trash racks attached to a concrete spillway structure should be secured with stainless steel anchor bolts.

SECTION B-12: OPERATION AND MAINTENANCE

This section presents general operation, maintenance and inspection guidelines for principal spillways and components. However, these guidelines are not intended to be all-inclusive. Specific structures may require special measures not discussed here. The engineer is responsible for determining what, if any, additional items are necessary.

1. Spillway structures should be cleared of debris periodically and after any significant rainfall event where inspection reveals a significant blockage.

2. During low water conditions, concrete spillway structures should be inspected to decide if water is passing through any joints or other structure contacts and to identify any cracks, spalling, broken or loose sections. Any cracked, spalled, broken or loose sections should be cleaned and refilled with an appropriate concrete patching material. A professional engineer should be consulted to repair extensive leakage, spalls or fractures.

3. Outlet protection (stilling basins) and discharge channels should be cleared of brush at least once per year.

4. Trash racks and locking mechanisms should be inspected and tested periodically to make sure they are intact and operative.

5. All sluice gates (or other types of gates or valves used to drain an impoundment) should be operated periodically to insure proper function. The gate and stem should be periodically lubricated and all exposed metal should be painted to protect it from corrosion.

6. Any repairs made to the principal spillway (riser or barrel) should be reviewed by a professional engineer. Vertical trenching to expose the barrel should not be allowed under any circumstances. The trench side slopes should be stepped back at a 2:1 slope, minimum.

SECTION B-13: REFERENCES

American Society of Civil Engineers. *Stormwater Detention Outlet Control Structures*. Task Commission On the Design of Outlet Control Structures, ASCE. New York, NY: 1985.

Brater, E.F., and H.W. King. *Handbook of Hydraulics*. 6th ed. New York: McGraw Hill Book Company, 1976.

Debo, T.N., and A.J. Reese. *Municipal Stormwater Management*. 1995.

Federal Highway Administration. *Debris-Control Structures*. Hydraulic Engineering Circular No. 9, 1971.

Federal Highway Administration. *Hydraulic Design of Highway Culverts*. Hydraulic Design Series, No. 5, 1985.

Maryland Department of the Environment-Dam Safety Division, *DOs and DON'Ts for Pond Construction*, May 1997.

Rossmiller, R.L. "Outlet Structure Hydraulics for Detention Facilities". *Proceedings of the International Symposium On Urban Hydrology, Hydraulics and Sediment Control*. University of Kentucky, KY: 1982.

Sandvik, A. "Proportional Weirs for Stormwater Pond Outlets." *Civil Engineering*. ASCE. pp. 54-56. March, 1985.

U.S. Department of the Interior Bureau of Reclamation. ACER Technical Memorandum No. 9, *Guidelines for Controlling Seepage Along Conduits Through Embankment*. 1987.

USDA Soil Conservation Service T.R. 5, Appendix C. *Evaluation of the Settlement Ratio for Positive Projecting Conduits*.

USDA Soil Conservation Service. Technical Note Series No. 709, *Dimensioning of Filter-Drainage Diaphragms for Conduits According to TR-60*. April, 1985.

U. S. Department of the Interior, Bureau of Reclamation. *Design of Small Dams*. 1987.

USDA–Natural Resource Conservation Service. *Engineering Field Manual*

USDA–Natural Resource Conservation Service. *National Engineering Handbook.*

Virginia Erosion and Sediment Control Handbook (VESCH) 1992 edition.

APPENDIX C
VEGETATED EMERGENCY SPILLWAY

VERSION 1.0
March 1, 2011

[NOTE: Could use a better photo more clearly showing the emergency spillway in the context of the dam.]

SECTION C-1: DESCRIPTION OF PRACTICE

A vegetated emergency spillway is an open channel, usually trapezoidal in cross-section, that is constructed beside an embankment. It consists of an *inlet channel*, a *control section*, and an *exit channel*, and is lined with erosion-resistant vegetation. The purpose of a vegetated emergency spillway is to convey flows that are greater than the principal spillway's design discharge at a non-erosive velocity to an adequate receiving channel.

SECTION C-2: PERFORMANCE CRITERIA

Not applicable.

SECTION C-3: PRACTICE APPLICATIONS AND FEASIBILITY

A vegetated emergency spillway is appropriate to use when the required maximum design flood volume may exceed the capacity of the principal spillway system. A vegetated emergency spillway may also be used as a safety feature to pass flood flows when or if the principal spillway becomes clogged.

SECTION C-4: ENVIRONMENTAL AND COMMUNITY CONSIDERATIONS

The adjacent topography (steepness of the abutments), the existing or proposed land use, and other factors (such as a roadway over the embankment) influence the design and construction of a vegetated emergency spillway.

Vegetated emergency spillways must be built in existing ground or "cut. Even though an emergency spillway helps to extend the life expectancy of an impoundment and lowers the associated downstream hazard conditions, it should *not* be located on any portion of the embankment fill. Therefore, additional land disturbance beside the embankment must be accounted for during the planning stages of a project. Sometimes, an emergency spillway may not be practical due to this or other considerations.

If site topography or other constraints preclude the use of a vegetated emergency spillway in "cut," the principal spillway can be oversized to pass the additional flows or an *armored* emergency spillway may be provided. A cost analysis may be helpful to aid in the selection of the spillway type. If armoring is chosen, then riprap, concrete or any other permanent, nonerodible surface may be used. Note, however, that **an armored emergency spillway over the top of an embankment should be designed by a qualified professional**.

Vegetated emergency spillways should be used only where the soils and topography will permit safe discharge of the peak flow at a point downstream from the embankment and at a velocity that will not cause appreciable erosion. Additional flood storage in the reservoir may be provided to reduce the design flow or the frequency with which the spillway is used.

SECTION C-5: DESIGN APPLICATIONS AND VARIATIONS

(?)

SECTION C-6: SIZING AND TESTING GUIDELINES

Not applicable.

SECTION C-7: DESIGN CRITERIA

A vegetated emergency spillway is designed to convey a pre-determined design flood discharge without excessive velocities and without overtopping the embankment. **The maximum design water surface elevation through the emergency spillway should be at least 1 foot lower than the settled top of the embankment**. **In general, it is recommended that a vegetated emergency spillway be designed to operate during the 100-year frequency storm.**

Layout

Vegetated spillways should be constructed in undisturbed earth in the abutments at one or both ends of an earthen embankment or over a topographic saddle anywhere on the periphery of the basin. **The channel should be excavated into undisturbed earth or rock and the water surface, under maximum design flood discharge, should be confined by undisturbed earth or rock**.

Excavated spillways consist of three elements: (1) an *inlet channel*, (2) a *level section*, and(3) an *exit channel* (see **Figure C-1**). Flow enters the spillway through the inlet channel. The depth of flow, H_p , located upstream from the level section, is controlled in the level section and then discharged through the exit channel. Flow in the inlet channel is *sub-critical*. Flow in the exit channel can be either *critical* or *supercritical*. **The control section is, therefore, the point on the spillway where the flow passes through critical depth**. It is recommended that the control section be installed close to the intersection of the earthen embankment and the emergency spillway centerlines.

The topography must be carefully considered when constructing an emergency spillway. The alignment of the exit channel must be straight to a point far enough below the embankment to insure that any flow escaping the exit channel cannot damage the embankment. This may result in additional clearing and/or grading requirements beside the abutments, property line, etc.

Figure C-1 shows profiles along the centerline of a typical vegetated spillway. To reduce losses through the inlet channel, the cross-sectional area of flow in the inlet channel should be large in comparison to the flow area at the control section. Where the depth of the channel changes to provide for the increased flow area, the bottom width should be altered gradually to avoid abrupt changes in the shape of the sloping channel banks.

The exit channel must have an adequate slope to discharge the peak flow within the channel. However, the slope must be no greater than that which will produce maximum permissible velocities for the soil type or the planned grass cover.

Soil Types and Vegetative Cover

The type of soil and vegetative cover used in an emergency spillway can be used to establish the spillway design dimensions. Soil types are classified as *erosion resistant* and *easily erodible*. ***Erosion resistant soils*** are those with a high clay content and high plasticity. Typical soil textures for erosion resistant soils are silty clay, sandy clay, and clay. ***Easily erodible soils*** are those with a high content of fine sand or silt, and a low plasticity or non-plastic. Typical soil textures for easily erodible soils are fine sand, silt, sandy loam, and silty loam. **Table C-1** provides permissible velocities for a vegetated spillway based on its soil type, vegetated cover, and exit channel slope. The maximum permissible velocity may be increased by 25% when the anticipated average use is less than once in 10 years.

Table C-1. Permissible Velocities for Vegetated Spillways [1]

Vegetative Cover	Permissible Velocity [2] (ft./sec.)			
	Erosion Resistant Soils [3]		Easy Erodible Soils [4]	
	Slope of Exit Channel		Slope of Exit Channel	
	0 - 5%	5 – 10%	0 – 5%	5 – 10%
Bermuda Grass Bahiagrass	8	7	6	5
Buffalograss Kentucky Bluegrass Smooth Bromegrass Tall Fescue Reed Canary Grass	7	6	5	4
Sod Forming Grass-Legume Mixtures	5	4	4	3
Lespedeza Weeping Lovegrass Yellow Bluestem Native Grass Mixtures	3.5	3.5	2.5	2.5

[1] USDA-NRCS TP-61
[2] Increase values 25 percent when the anticipated average use of the spillway is not more frequent than once in 10 years.
[3] Those with a high clay content and high plasticity. Typical soil textures are silty clay, sandy clay, and clay
[4] Those with a high content of fine sand or silt and lower plasticity or non-plastic. Typical soil textures are fine sand, silt, sandy loam, and silty loam.

Source: USDA-NRCS Engineering Field Manual

The *type* and *length of vegetative cover* affect the design of a vegetated spillway. Vegetation provides a *degree of retardance* to the flow through the spillway. **Table C-2** gives retardance values for various heights of vegetative cover. Retardance for a given spillway will depend mostly upon the *height* and *density* of the cover chosen. Generally, after the cover is selected, "retardance with a good, uncut condition" should be used to find the capacity. Since a condition offering less protection and less retardance exists during the establishment period and after mowing, a lower degree of retardance should be used when designing for stability. Refer to the sample exercises for the design of vegetated spillways found in **Chapter 13** of the *Virginia Stormwater Management Handbook* (2009). **[NOTE: Be sure this chapter reference is correct.]**

Table C-2. Retardance Classifications for Vegetative Channel Linings			
Retardance	**Vegetative Cover**	**Stand**	**Condition**
B	Tall Fescue	Good	Unmowed – 18”
	Sericea Lespedeza	Good	Unmowed – 18”
	Grass-Legume Mixture	Good	Unmowed – 20”
	Small Grains, Mature	Good	Uncut – 19”
	Bermuda Grass	Good	Tall – 12”
	Reed Canary Grass	Good	Mowed – 14”
C	Bermuda Grass	Good	Mowed – 6”
	Redtop	Good	Headed – 18”
	Grass-Legume Mixture – Summer	Good	Unmowed – 7”
	Kentucky Bluegrass	Good	Headed – 9”
	Small Grains, Mixture	Poor	Uncut – 19”
	Tall Fescue	Good	Mowed – 6”
D	Bermuda Grass	Good	Mowed – 2.5”
	Red Fescue	Good	Headed – 15”
	Grass-Legume Mixture – Spring and Fall	Good	Mowed – 2”
	Sericea Lespedeza	Good	Mowed – 2”

Source: USDA-NRCS

Hydraulic Design

The hydraulic design of earthen spillways can be simplified if the effects of *spillway storage* are ignored. Stormwater facilities designed for compliance with state or local stormwater management regulations are typically small, resulting in minimal storage effects on the flood routing.

Two design calculation procedures are presented in **Chapters 16 and 17** of the *Virginia Stormwater Management Handbook* (2009) **[NOTE: Be sure these chapter references are correct.]**. The first (Procedure 1) is a conservative design procedure which is also found in the *Virginia Erosion & Sediment Control Handbook* (VESCH) 1992 edition, (Std., & Spec. 3.14). This procedure is typically acceptable for stormwater management basins. The second method (Procedure 2) utilizes the roughness, or retardance, and durability of the vegetation and soils within the vegetated spillway. This second design is appropriate for larger or regional stormwater facilities where the construction inspection and permanent maintenance are more readily enforced. These larger facilities typically control relatively large watersheds and are located such that the stability of the emergency spillway is essential to safeguard downstream features.

If the inflow is known (from the post-developed condition hydrology) and either the desired maximum water surface elevation, or the approximate width of the proposed emergency spillway (established by the embankment geometry and the adjacent topography), then the relationship between H_p, the depth of flow through the emergency spillway, and b, the emergency spillway bottom width, can be established using design Procedure 1 (**Chapters 16 and 17**) **[NOTE: Be sure these chapter references are correct.]** and **Table 16-12**. **[NOTE: This note refers to a table on page 5-77 in the "Engineering Calculations" Chapter of the 1999 Virginia Stormwater Management Handbook. Be sure to update this reference to the new Table numbers in the revised Handbook (2009).]**

If the required discharge capacity, *Q*, permissible velocity, *V* (see **Table C-1**), degree of retardance, *C* (see **Table C-2**), and the natural slope of the exit channel, s_o , are known, then the bottom width, *b*, of the level and exit sections and the depth of flow, H_p , may be computed using design Procedure 2 (**Chapters 16 and 17**) and **Table 16-13**. However, Tables 16-13(a-d) is not appropriate for bottom widths less than 8 feet. **[NOTE: This note refers to the tables on page 5-78 through 5-80 in the "Engineering Calculations" Chapter of the 1999 Virginia Stormwater Management Handbook. Be sure to update this reference to the new Table numbers in the revised Handbook (2009).]**

The hydraulic design of a vegetated emergency spillway should comply with the following:

1. The maximum permissible velocity for vegetated spillways should be selected using **Table C-1**.

2. The slope range of the exit channel provided in **Table 16-11 (Chapter 16)** **[NOTE: This note refers to a table on page 5-62 in the "Engineering Calculations" Chapter of the 1999 Virginia Stormwater Management Handbook. Be sure to update this reference to the new Table numbers in the revised Handbook (2009).]**, is a minimum slope range needed to insure ***supercritical*** flow in the exit channel.

3. Spillway side slopes should be no steeper than 3H:1V unless the spillway is excavated into rock.

4. For a given H_p , a decrease in the exit slope from s_o, as given in **Table 16-11 (Chapter 16)**, decreases the spillway discharge, but increasing the exit slope from s_o does not increase discharge.

5. The exit channel should have a straight alignment and grade and, at a minimum, the same cross-section as the control section.

6. The inlet channel should have a straight alignment and grade.

7. The selected bottom width of the spillway should not exceed 35 times the design depth of flow. Where this ratio of bottom width to depth is exceeded, the spillway is likely to be damaged by meandering flow and accumulated debris. Whenever the required bottom width of the spillway is excessive, consideration should be given to the use of a spillway at each end of the dam. The two spillways do not need to be of equal width if their total capacity meets design requirements. If the required discharge capacity exceeds the ranges shown in the referenced tables, or topographic conditions preclude the construction of the exit channel

bottom using a slope that falls within the designated ranges, alternate design procedures should be used.

8. Vegetated emergency spillways should be designed for use with the 100-year frequency storm or greater.

SECTION C-8: REGIONAL AND CLIMATE DESIGN VARIATIONS

Not applicable.

SECTION C-9: TYPICAL GRAPHICAL DETAILS

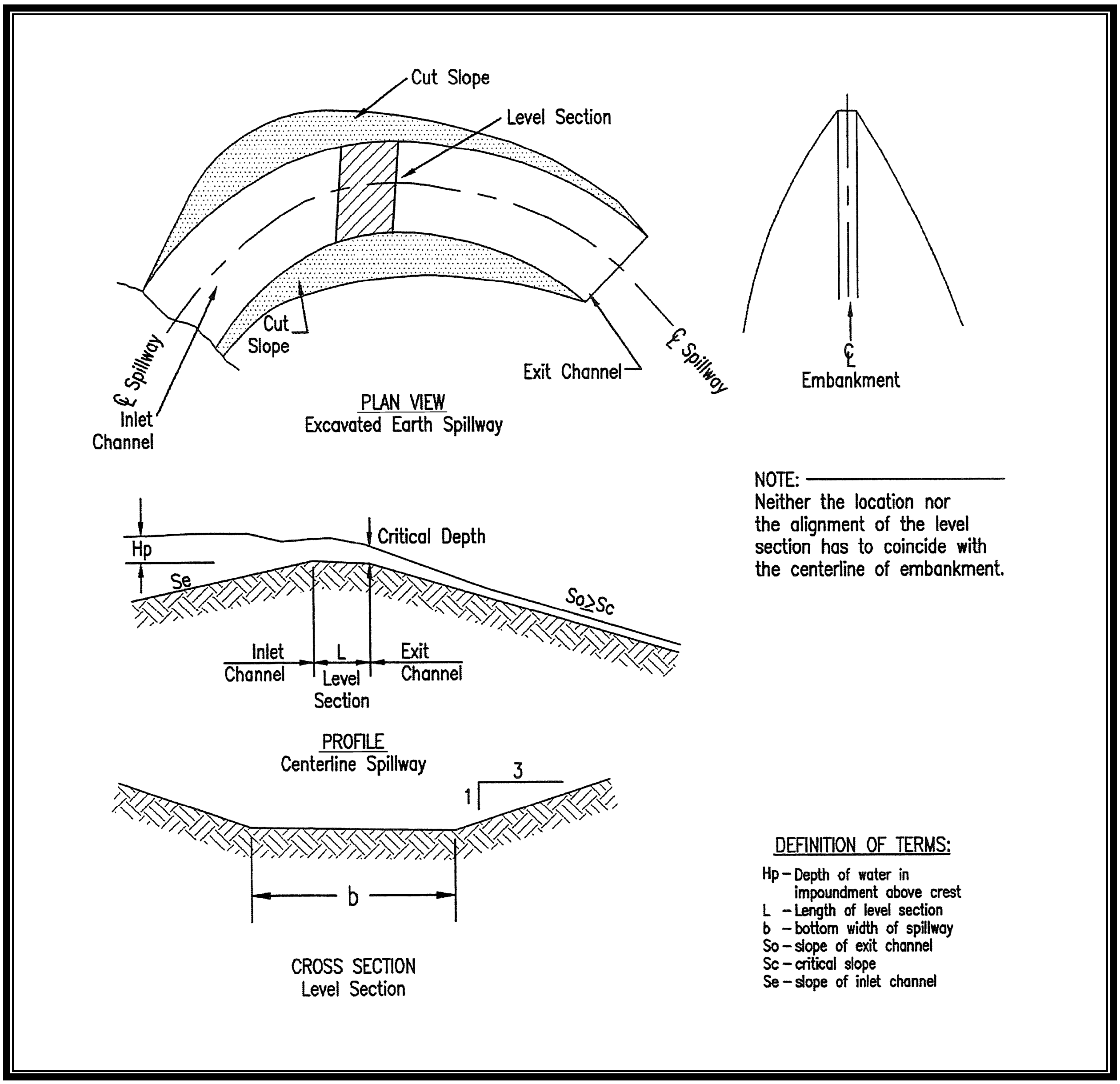


Figure C-1. Typical Plan and Profiles Along the Centerline of an Earth Spillway

Figure C-2. Emergency Spillway Draining into a Concrete Channel

[NOTE: Not sure how appropriate this photo is, since this Appendix focuses on *vegetated* emergency spillways and does not address this type of design. Perhaps we should delete this photo?]

SECTION C-10: MATERIAL SPECIFICATIONS

Not applicable. (?)

SECTION C-11: CONSTRUCTION SEQUENCE AND INSPECTION

Overall, widely acceptable construction standards and specifications for a vegetated emergency spillway on an embankment, such as those developed by the USDA-Natural Resource Conservation Service or the U. S. Army Corps of Engineers, should be followed. Further guidance can be found in the USDA-NRCS *Engineering Field Manual* and the *National Engineering Handbook*. Specifications for all earthwork and any other related work should conform to the methods and procedures that apply to the site and the purpose of the structure. The specifications should also satisfy any requirements of the local government.

Installation of a vegetated emergency spillway consists of the following: (a) excavating the proper bottom width and side slopes according to the approved plan; (b) backfilling with 12 inches of topsoil (minimum); and (c) stabilizing the area following the *Virginia Erosion and Sediment Control Handbook (*VESCH, 1992).

SECTION C-12: OPERATION AND MAINTENANCE

The following maintenance and inspection guidelines are recommendations. The engineer must decide if additional criteria are needed based upon the size and scope of the facility.

1. Vegetated emergency spillway channels should be mowed concurrently with the embankment and should not be cut to less than 6 to 8 inches in height.

2. The emergency spillway approach and discharge channels should be cleared of brush and other woody growth periodically.

3. After any flow has passed through the emergency spillway, the spillway crest (control section) and exit channel should be inspected for erosion. All eroded areas should be repaired and stabilized.

SECTION C-13: REFERENCES

USDA Natural Resource Conservation Service. *Engineering Field Manual*.

USDA Natural Resource Conservation Service. *National Engineering Handbook*.

USDA Natural Resource Conservation Service. *Technical Release No. 60: Earth Dams and Reservoirs*.

U. S. Department of the Interior. *Design of Small Dams*. 1987.

Virginia Erosion and Sediment Control Handbook (VESCH), 1992.

APPENDIX D
SEDIMENT FOREBAY

VERSION 1.0
March 1, 2011

SECTION D-1: DESCRIPTION OF PRACTICE

A sediment forebay is a settling basin or plunge pool constructed at the incoming discharge points of a stormwater BMP. The purpose of a sediment forebay is to allow sediment to settle from the incoming stormwater runoff before it is delivered to the balance of the BMP. A sediment forebay helps to isolate the sediment deposition in an accessible area, which facilitates BMP maintenance efforts.

SECTION D-2: PERFORMANCE CRITERIA

Not applicable.

SECTION D-3: PRACTICE APPLICATIONS AND FEASIBILITY

A sediment forebay is an essential component of most impoundment and infiltration BMPs including retention, detention, extended-detention, constructed wetlands, and infiltration basins.

A sediment forebay should be located at each inflow point in the stormwater BMP. Storm drain piping or other conveyances may be aligned to discharge into one forebay or several, as appropriate for the particular site. Forebays should be installed in a location which is accessible by maintenance equipment.

<u>Water Quality</u>

A sediment forebay not only serves as a maintenance feature in a stormwater BMP, it also enhances the pollutant removal capabilities of the BMP. The volume and depth of the forebay work in concert with the outlet protection at the inflow points to dissipate the energy of incoming stormwater flows. This allows the heavier, course-grained sediments and particulate pollutants to settle out of the runoff. **Note that for the BMPs listed in this handbook, the target pollutant removal efficiencies have been established assuming sediment forebays are included in the design**. Therefore, no additional pollutant removal efficiency is warranted for using a sediment forebay.

<u>Channel Erosion Control and Flood Control</u>

An “on line” BMP designed for flood control and channel erosion control is subject to the natural bed material (sediment) load, plus any bed load increases due to higher velocities in the upstream channels. This is especially true for regional facilities where the upstream channel is used to convey the increased developed condition flows. In such cases, the sediment forebay becomes an essential facility maintenance component since it serves to simplify clean-out operations.

Studies indicate that a well-designed retention basin will function for 20 to 25 years before it needs dredging. This implies a gradual sediment accumulation process. A concern regarding stormwater basins is that the landowners will probably change at least once during that 20 to 25-year period. The new owners may not be aware of the maintenance requirements and, may therefore, neglect to maintain the facility. Sediment will then continue to accumulate and will eventually fill the BMP pool volume.

A sediment forebay, however, is designed to trap the sediments within a confined area. This causes a more rapid sediment accumulation. Studies indicate that for a typical mixed-use watershed, sediment should be removed from the forebay every three-to-five years. Despite this frequency, removal of sediment from the forebay should be less costly over the same time period than a one time cleaning of the entire basin. This is due in part to the fact that removing sediment from the forebay is a much simpler operation than that of an entire stormwater basin or pond. The sediment is confined to strategic forebay locations with easy access. Furthermore, the more frequent and less expensive schedule will likely become a regular part of the operation and maintenance efforts of the owners.

SECTION D-4: ENVIRONMENTAL AND COMMUNITY CONSIDERATIONS

Not applicable. (?)

SECTION D-5: DESIGN APPLICATIONS AND VARIATIONS

Not applicable.

SECTION D-6: SIZING AND TESTING GUIDELINES

The sediment forebay should be sized to hold 0.25 inches of runoff per impervious acre of contributing drainage area, with an absolute minimum of 0.1 inches per impervious acre. The volume of the sediment forebay is not in addition to the required volume of the retention basin permanent pool, but rather as part of the required pool volume. For dry facilities, the forebay does not represent available storage volume if it remains full of water. A dry forebay must be carefully designed to avoid the resuspension of previously deposited sediments. The 0.1 to 0.25 impervious watershed inches is guidance for ideal performance. For smaller stormwater facilities, a more appropriate sizing criterion of 10% of the total required pool or detention volume may be more practical. This volume should be 4 to 6 feet deep to adequately dissipate turbulent inflow without resuspending previously deposited sediment (Center for Watershed Protection, 1995).

[NOTE: Apart from this sizing criteria, there are no other specific dimensions listed anywhere in this specification. Is this sufficient for design?]

SECTION D-7: DESIGN CRITERIA

The most attractive aspect of a sediment forebay is its isolation from the rest of the facility. To create this separation, an earthen berm, or a gabion, concrete, or riprap wall can be constructed along the outlet side of the forebay. A designed overflow section should be constructed on the top of the separation to allow flow to exit the forebay at non-erosive velocities during the 2-year and 10-year frequency design storms. The overflow section may be set at the permanent pool elevation or the extended-detention volume elevation. It may also be designed to serve as a spillover for the forebay if the forebay is set at a higher elevation than the second or remaining cell.

The use of an aquatic bench with emergent vegetation around the perimeter will help with water quality as well as provide a safety feature for large forebays (used on large lake BMPs or retrofits).

Maintenance

Direct access to the forebay should be provided to simplify maintenance. Provision of a hardened access or staging pad adjacent to the forebay is also beneficial. Such an area helps protect the forebay and basin from excessive erosion resulting from operation of the heavy equipment used for maintenance. Installing block pavers or similar material can harden the pad area. Also, a hardened bottom to the forebay will help avoid over excavation during clean out operations.

In addition, a fixed, vertical, sediment depth marker should be installed in each sediment forebay to measure the sediment deposition. The sediment depth marker will allow the owner to monitor the accumulation and anticipate maintenance needs. Clean out frequency will vary depending on the conditions of the upstream watershed and the given site.

SECTION D-8: REGIONAL AND CLIMATE DESIGN VARIATIONS

Not applicable. (?)

SECTION D-9: TYPICAL GRAPHICAL DETAILS

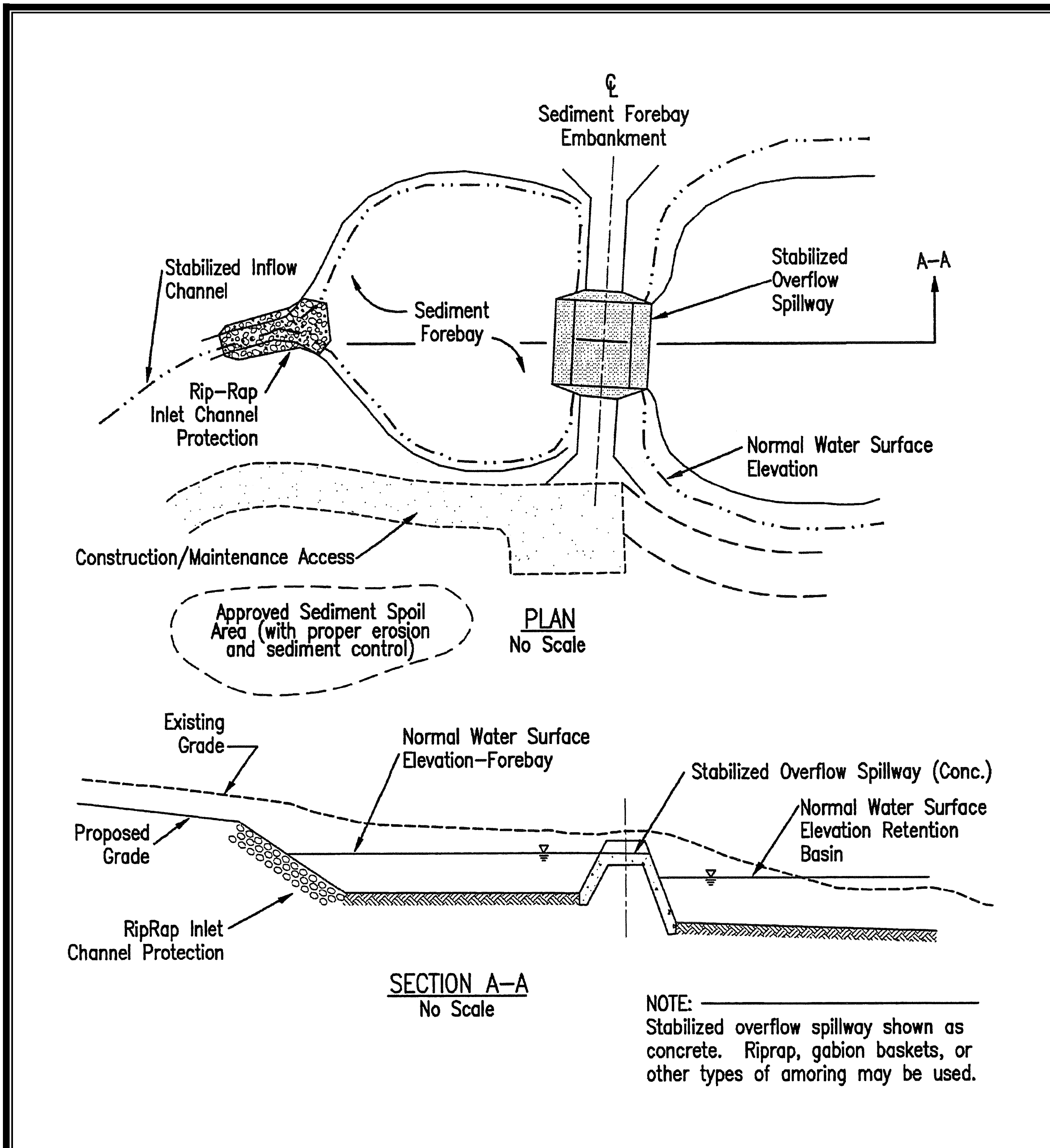


Figure D-1. Typical Sediment Forebay Plan and Section

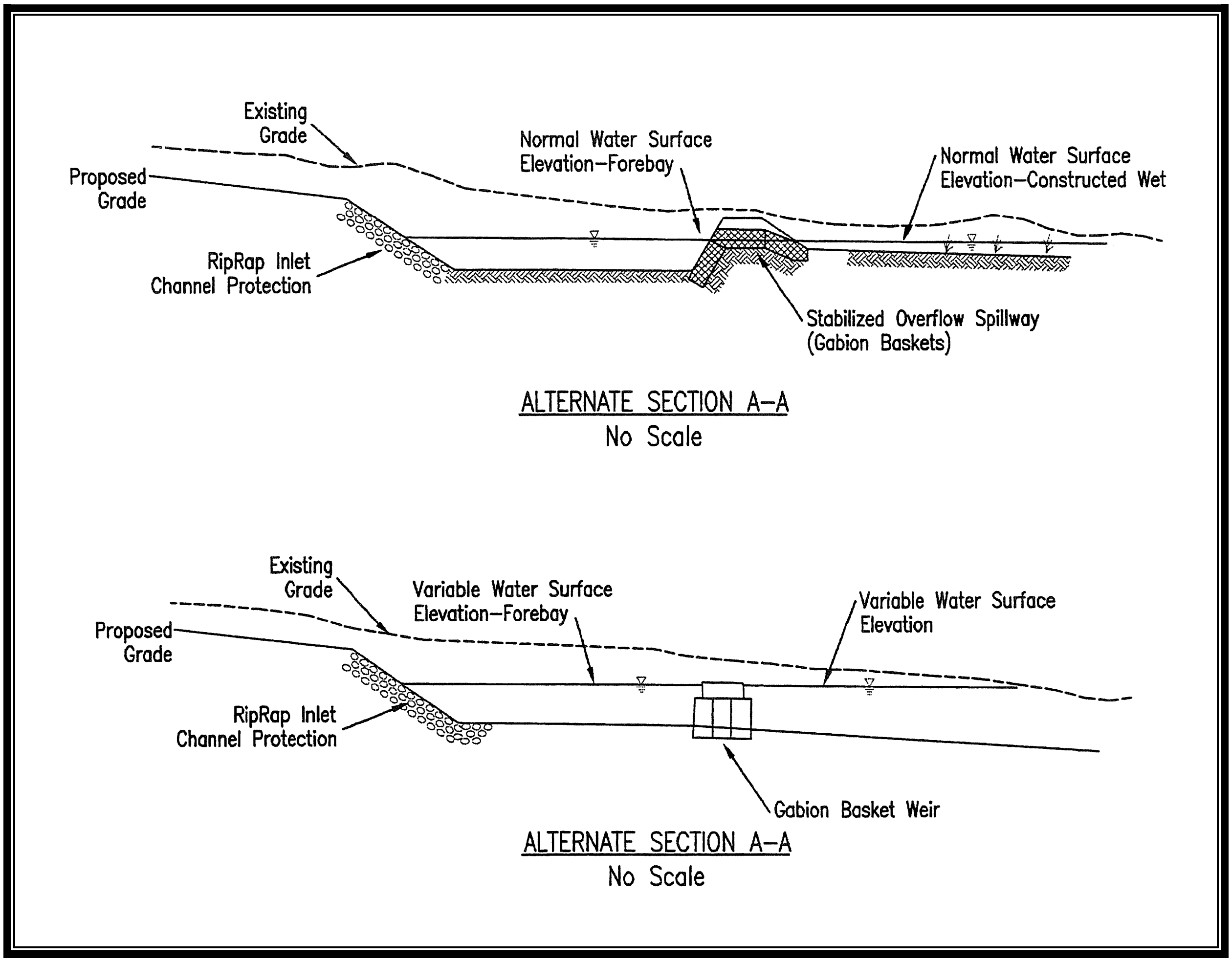


Figure D-2. Typical Sediment Forebay Sections

Figure D-3. Sediment Forebay Constructed with a Submerged Rip-Rap Weir

SECTION D-10: MATERIAL SPECIFICATIONS

Not applicable. (?)

SECTION D-11: CONSTRUCTION SEQUENCE AND INSPECTION

Not applicable. (?)

SECTION D-12: OPERATION AND MAINTENANCE

In general, sediment should be removed from the forebay every 3 to 5 years, or when 6 to 12 inches have accumulated, whichever comes first. To clean the forebay, draining or pumping and a possible temporary partial drawdown of the pool area may be required. Refer to the *Virginia Erosion and Sediment Control Handbook* (1992) for proper dewatering methods.

To reduce costs associated with hauling and disposing of dredged material, a designated spoil area should be approved and identified on the site during initial design and development of the project.

SECTION D-13: REFERENCES

Not applicable. (?)

APPENDIX E
LANDSCAPING

VERSION 1.0
March 1, 2011

SECTION E-1: DESCRIPTION OF PRACTICE

Landscaping is the placement of vegetation in and around stormwater management BMPs. The purpose of landscaping is to help stabilize disturbed areas, enhance the pollutant removal capabilities of a stormwater BMP and improve the overall aesthetics of a stormwater BMP.

SECTION E-2: PERFORMANCE CRITERIA

Not applicable.

SECTION E-3: PRACTICE APPLICATIONS AND FEASIBILITY

A landscape plan is an integral part of any land development project. It provides guidance and specifications for the type, location, and number of planting units according to the various requirements of the development project. Landscaped areas can provide significant reductions in pollutant export from developed sites through biological uptake of nutrients, sediment trapping, filtering, and infiltration. A landscape plan may need one or all of the following:

1. Minimum green space or other requirements per local zoning or stabilization ordinances.
2. Natural and manmade vegetative buffer requirements between differing land uses or between developed land and natural resources.

3. Landscaping and stabilization requirements for stormwater management BMPs.

This minimum specification focuses on landscaping and stabilization requirements for stormwater management BMPs and their associated buffer areas. This standard may also be appropriate for other landscaping applications used in plan and specification preparation.

Certain BMPs, such as constructed wetlands, retention basins with an aquatic bench, *enhanced* extended detention basins with a shallow marsh, bioretention facilities, etc., require very specific plant materials and handling specifications. Refer to the minimum standards found on this web site for additional criteria applicable to specific BMP designs.

For stormwater management purposes, landscaping is considered an integral component of a structural BMP. While the benefit realized from landscaping may be difficult to measure, it is widely accepted that the biological processes occurring in detention and retention BMPs are greatly enhanced by using vegetation. **The target pollutant removal efficiencies assigned to BMPs approved for use in Virginia are based on the use of vegetative practices within the BMP buffer areas and the various BMP planting zones**. The vegetative practices should be specified in a landscape plan as part of the overall BMP and site construction documents.

SECTION E-4: ENVIRONMENTAL AND COMMUNITY CONSIDERATION

Not applicable.

SECTION E-5: DESIGN APPLICATIONS AND VARIATIONS

Not applicable.

SECTION E-6: SIZING AND TESTING GUIDELINES

Not applicable.

SECTION E-7: DESIGN CRITERIA

The landscape plan for a stormwater BMP depends on the BMP being used. However, there are key components to any landscape plan that help assure its overall success. The following section describes these components.

A landscape plan for a stormwater management BMP should contain the following, at a minimum:

Plant Species Selection

Plants selected for a stormwater BMP must tolerate urban stresses such as pollutants, along with variable soil moisture and ponding fluctuations, climate, soils, and topography. Virginia has three distinct physiographic regions that reflect changes in soils and topography: Coastal Plain, Piedmont, and Appalachian and Blue Ridge regions. See **Figure E-1**.

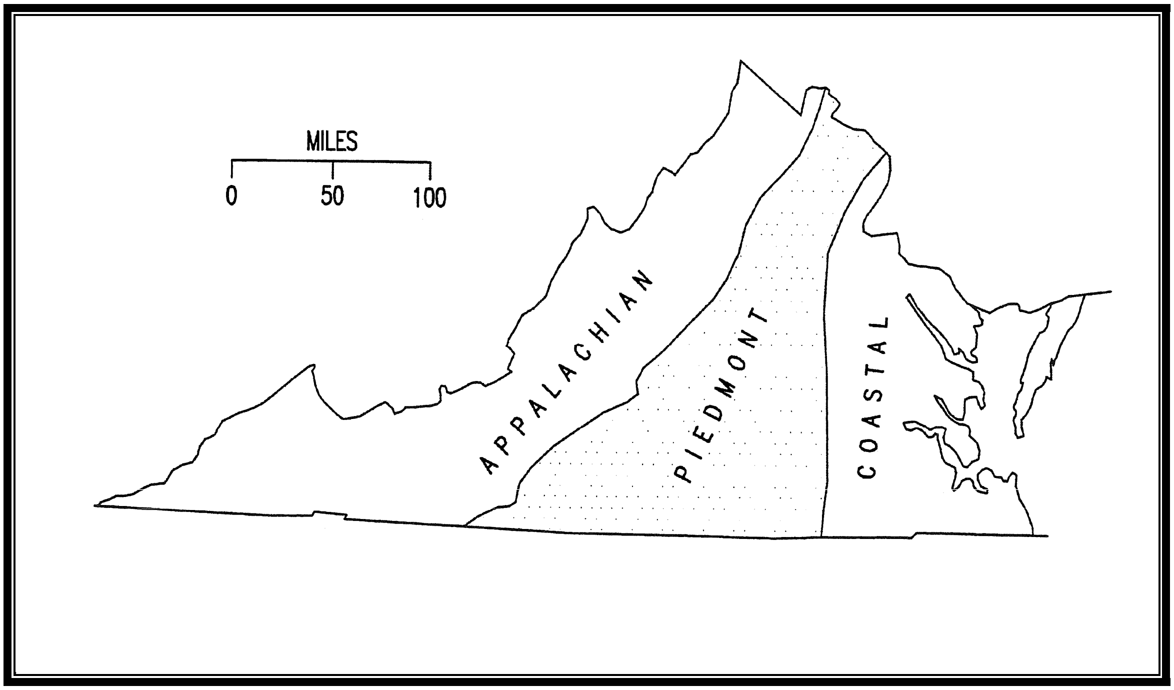


Figure E-1. Virginia Physiographic Regions

Plant selection should also be based on the planting zones within the BMP. Various zones exist within and around a stormwater impoundment and each represents a different inundation frequency and soil moisture condition. **Figure E-2** shows a schematic cross-section of the six planting zones. Designers should select appropriate plant and tree species based on the characteristics of each zone, local soil conditions, sun and wind exposure levels, and intended secondary uses of the buffer area. The planting zones can be classified as follows:

Zone 1: Deep Water Areas: This zone is submerged beneath 18 inches to 6 feet of water. It supports submerged aquatic vegetation such as pondweed, coontail, wild celery, etc., and floating vegetation such as duckweed. Plants can actively remove metals from the water and provide food and habitat for invertebrates at the bottom of the food cycle. This zone may be present in retention basins, constructed wetlands, and in sediment forebays and micro-pools of extended-detention and *enhanced* extended-detention basins.

Zone 2: Shallow Water Area: This zone is 0-18 inches in normal depth and is the primary area for the establishment of emergent wetland plants. It may be present in retention basins, constructed wetlands, and *enhanced* extended-detention basins. This zone is divided into **low-marsh** and **high- marsh** sub-zones. The low-marsh extends from 6-18 inches in depth below the normal water surface. The high-marsh ranges from 6 inches below the normal water surface to the normal water surface. Vegetation in this zone can serve the following purposes:

- Enhances nutrient uptake,
- Reduces flow velocities to increase the rate of sediment deposition,
- Reduces resuspension of bottom sediments,
- Provides food and cover for wildlife,
- Provides habitat for predatory insects and to serve as a check for mosquitoes,
- Reduces shoreline erosion, and
- Improves aesthetics

Suggested plants for this zone include common three-square, soft-stem bulrush, pickerelweed, arrow arrum, sedges, and others.

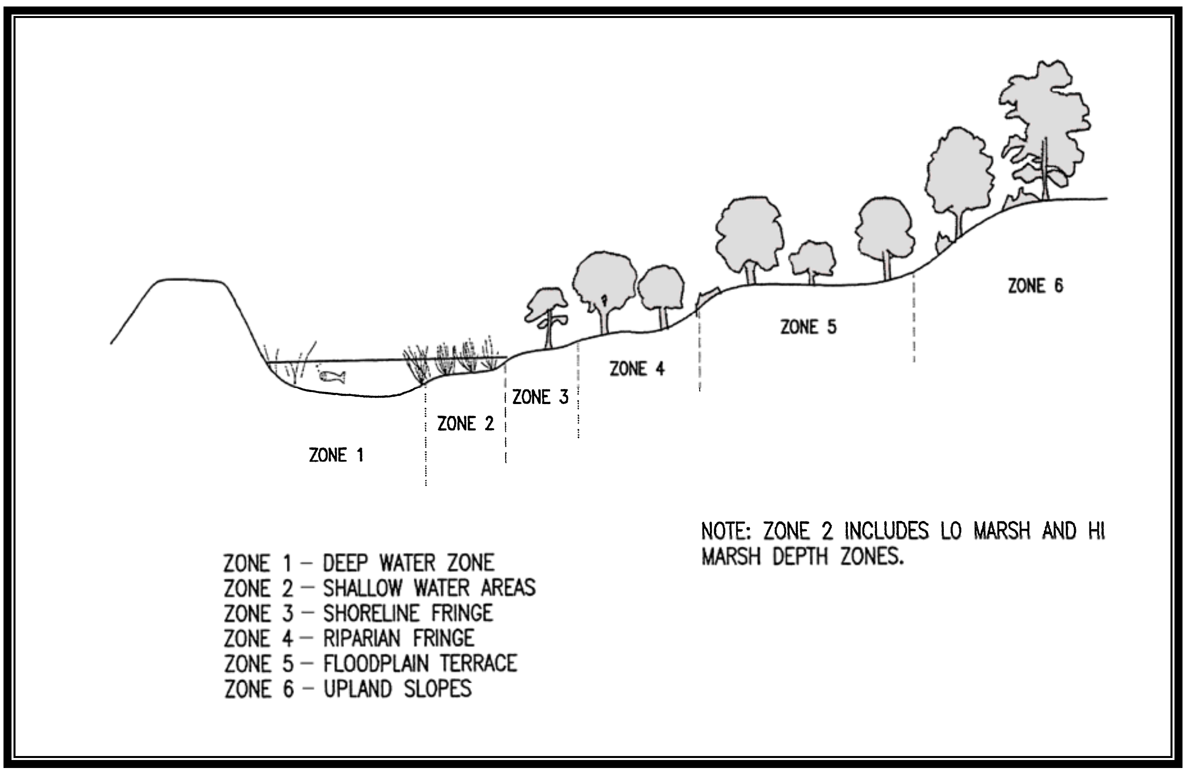


Figure E-2. Planting Zones for Typical Stormwater BMPS

Zone 3: Shoreline Fringe: This zone is regularly inundated during runoff-producing storm events and may remain saturated due to the proximity of the permanent pool. However, plants must be tolerant of periodic drying, especially during the summer months. This zone extends from the normal water surface to about 1 foot above the normal water surface for retention basins and constructed wetlands. It also continues up to the maximum extended-detention volume elevation for extended-detention and *enhanced* extended-detention basins. The vegetation in this zone may serve the following purposes:

- Stabilizes the shoreline,
- Improves aesthetics,
- Limits shoreline access by people and animals (geese),
- Provides food, cover, and nesting for wildlife, and
- Provides shade

Figure E-3. Rough shoreline edge and aquatic bench

Recommended species for this zone include herbaceous vegetation such as soft-stem bulrush, pickerelweed, rice cutgrass, sedges, and others. It also includes trees such as black willow and river birch and shrubs such as chokeberry.

Zone 4: Riparian Fringe Area: This zone is only briefly inundated during storms. It generally includes the upper storage areas of extended-detention basins (above the water quality or channel erosion control volume) and the lower basin areas of dry detention basins. It experiences both wet and dry soil conditions and periodic inundation. The vegetation in this zone may serve the following purposes:

- Reduce resuspension of newly deposited sediments,
- Prevent erosion, and
- Provide habitat and food for wildlife,

A variety of trees, shrubs, and ground covers can be used in this zone, including black willow, river birch, red chokeberry, green ash, sweetgum and others.

Zone 5: Floodplain Terrace: This zone experiences inundation only during large storms. It is generally between the 2-year and 100-year water surface elevations. Plant species native to floodplains usually grow well in this zone. Plants selected for the floodplain terrace should have the following traits:

- Ability to provide erosion control on steep slopes,
- Ability to survive periodic mowing,
- Ability to withstand exposure and compacted soil, and
- Require minimal maintenance

Zone 6: Upland Areas: This zone seldom, if ever, experiences inundation and may include any buffer areas required for stormwater basins. Selection of plant species in this zone typically depends on local soil conditions and the intended secondary uses of the area. Refer to **Table E-4** for a plant guide.

Preservation of Existing Vegetation

Although there are many reasons to minimize land disturbance associated with development, one of the greatest benefits may be the reduced runoff associated with undisturbed ground. Existing vegetation helps prevent erosion, filters runoff, and allows stormwater to filter into the ground, which ultimately results in lower stormwater management costs. As for the economics of site development, planning for the selective preservation of vegetation on a site **before land disturbance** is much less costly than trying to reestablish it once it has been removed. This holds true for both labor and replacement costs. In addition, studies conducted by the U.S. Forest Service and others indicate that preserving mature vegetation on residential sites can increase property values by 30% (NVPDC, 1996).

For guidance on non-structural BMPs and vegetative practices in general, refer to the following references:

- *Piedmont Provinces Vegetative Practices Guide, NVPDC, 1996.*
- *Nonstructural BMP Handbook: A Guide to Nonpoint Source Pollution Prevention Measures, NVPDC, 1996.*
- *Vegetative Practices Guide for Nonpoint Source Pollution Management, HRPDC, 1992.*
- *Chesapeake Bay Local Assistance Manual, CBLAD, 1989.*
- *Riparian Buffer Modification & Mitigation Guidance Manual, 2003*
- *Virginia Erosion & Sediment Control Handbook (VESCH), 1992.**

* The *VESCH*, 1992 edition, also provides details for tree preservation during construction.

Choose Native Plants

When selecting plants, native plant species should be used, if possible. Nonnative plants may require more care to adapt to the hydrology, climate, exposure, soil and other conditions. Also, some nonnative plants can become invasive, especially those used for stabilization, and may ultimately choke out the native plant population. See **Tables E-1a and E-1b** for native plant recommendations.

Table E-1a. Native Tree/Shrub Guide for Stormwater Management Areas in the Mid-Atlantic -- USA Trees and Shrubs

Tree/Shrub	*Zone	Form	Available	Inundation Tolerance	Wildlife Value	Notes
American Beech *(Fagus grandifolia)*	5,6	Dec. Tree	No	no	High, mammals and birds.	Prefers shade and rich, well-drained soils.
American Holly *(Ilex opaca)*	5,6	Dec. Tree	Yes	some	High,songbirds, food, cover, nesting.	Coastal plain only. Prefers shade and rich soils.
American Hornbeam *(Carpinus caroliniana)*	4,5	Dec. Tree	Yes	yes	Moderate, food, browsing.	Most common in flood plains and bottom land of Piedmont and mountains.
Arrowwood Viburnum *(Viburnum dentatum)*	2,3,4	Dec. Shrub	Yes	no	High, songbirds and mammals.	Grows best in sun to partial shade.
Bald Cypress *(Taxodium distichum)*	3,4	Dec. Tree	Yes	yes	Little food value but good perching site for waterfowl.	Forested Coastal Plain wetlands. North of normal range. Tolerates drought.
Bayberry *(Myricia pensylvanica)*	4,5,6	Dec. Shrub	Yes	no	High, nesting, food cover. Berries last into winter.	Coastal Plain only. Roots fix N. Tolerates slightly acidic soil.
Bitternut Hickory *(Carya cordiformis)*	3,4,5	Dec. Tree	No	yes	High, food.	Moist soils or wet bottom land areas.
Black Cherry *(Prunus serotina)*	5,6	Dec. Tree	Yes	yes	High, fruit is eaten by many birds.	Temporarily flooded forested areas. Possible fungus infestation.
Black Walnut *(Juglans nigra)*	5,6	Dec. Tree	Yes	yes	High, food.	Temporarily flooded wetlands along flood plains. Well drained, rich soils.
Blackgum or Sourgum *(Nyssa sylvatica)*	4,5,6	Dec. Tree	Yes	yes	High, songbirds, egrets, herons, raccoons, owls.	Can be difficult to transplant. Prefers sun to partial shade.
Black Willow *(Salix nigra)*	3,4,5	Dec. Tree	Yes	yes	High, browsing and cavity nesters.	Rapid growth, stabilizes stream banks. Full sun.
Buttonbush *(Cephalanthus occidentalis)*	2,3,4,5	Dec. Shrub	Yes	yes	High, ducks and shorebirds. Seeds, nectar and nesting.	Full sun to partial shade. Will grow in dry areas.
Chestnut Oak *(Quercus prinus)*	5,6	Dec. Tree	No	no	High. Cover, browse and food.	Gypsy moth target. Dry soils.

****Zone 1: Submergent Aquatic Vegetation***
****Zone 2: Shallow Water Bench - 6-12 inches Deep***
****Zone 3: Shoreline Fringe - Regularly Inundated Area***
****Zone 4: Riparian Fringe - Periodically Inundated Area, Wet Soils***
****Zone 5: Floodplain Terrace - Infrequently Inundated, Moist Soils***
****Zone 6: Upland Slopes - Seldom or Never Inundated, Moist To Dry Soils***

Table E-1a (cont.)						
Tree/Shrub	***Zone**	**Form**	**Available**	**Inundation Tolerance**	**Wildlife Value**	**Notes**
Common Choke Cherry *(Prunus virginiana)*	5,6	Dec. Tree	no	some	High, birds, mammals. Fruit and cover.	Prefers drier conditions.
Common Spicebush *(Lindera benzoin)*	4,5	Dec. Shrub	yes	no	Very high, songbirds.	Shade and rich soils. Tolerates acidic soils. Good understory species.
Eastern Cottonwood *(Populus deltoides)*	4,5	Dec. Tree	yes	yes	Moderate, cover, food.	Shallow rooted, subject to windthrow. Invasive roots. Rapid growth.
Eastern Hemlock *(Tsuga conadensis)*	5,6	Conif. Tree	yes	yes	Moderate. Mostly cover and some food.	Tolerates all sun/shade conditions. Tolerates acidic soil.
Eastern Red Cedar *(Juniperus virginiana)*	4,5,6	Conif. Tree	yes	no	High. Fruit for birds. Some cover.	Full sun to partial shade. Common in wetlands, shrub bogs and edge of streams.
Elderberry *(Sambucus canadensis)*	4,5,6	Dec. Shrub	yes	yes	Extremely high for food and cover, for birds and mammals.	Full sun to partial shade.
Flowering Dogwood *(Cornus florida)*	4,5,6	Dec. Tree	no	yes	High, birds, food.	Prefers rich, moist soils. Dogwood anthracnose possible problem.
Fringe Tree *(Chionanthus viginicus)*	3,4,5	Dec. Shrub or small tree	yes	some	Moderate. Food and cover.	Full sun to partial shade. Tolerates acidic soil.
Green Ash, Red Ash *(Fraxinus pennysylvanica)*	4,5	Dec. Tree	yes	yes	Moderate, songbirds.	Rapid growing stream bank stabilizer. Full sun to partial shade.
Hackberry *(Celtis occidentalis)*	5,6	Dec. Tree	yes	yes	High, food and cover.	Full sun to partial shade.
Ironwood/ Hophornbeam *(Ostrya virginiana)*	5,6	Dec. Tree	yes	yes	Moderate, food and browse.	Tolerant of all sunlight conditions.
Larch, Tamarack *(Larix laricina)*	3,4	Conif. Tree	no	yes	Low, nest tree and seeds.	Rapid initial growth. Full sun, acidic boggy soils.
Loblolly Pine *(Pinus taeda)*	5,6	Conif. Tree	yes	yes	Moderate, food, nesting, squirrels.	Coastal Plain only. Tolerant of extreme soil conditions.

Zone 1:** ***Submergent Aquatic Vegetation
Zone 2:** ***Shallow Water Bench - 6-12 inches Deep
Zone 3:** ***Shoreline Fringe - Regularly Inundated Area
Zone 4:** ***Riparian Fringe - Periodically Inundated Area, Wet Soils
Zone 5:** ***Floodplain Terrace - Infrequently Inundated, Moist Soils
Zone 6:** ***Upland Slopes - Seldom or Never Inundated, Moist To Dry Soils

Table E-1a (cont.)						
Tree/Shrub	***Zone**	**Form**	**Available**	**Inundation Tolerance**	**Wildlife Value**	**Notes**
Mountain Laurel *(Kalmia latifolia)*	6	Evergreen	no	some	Low, cover, and nectar. Foliage is toxic to cattle and deer.	Partial shade, acidic soils.
Persimmon *(Diospyros virginiana)*	4,5,6	Dec. Tree	yes	no	Extremely high, birds, mammals.	Not shade tolerant. Well-drained soils.
Pin Oak *(Quercus palustris)*	4,5,6	Dec. Tree	yes	yes	High, mast. Tolerates acidic soil.	Gypsy moth target. Prefers sun to partial shade.
Red Chokeberry *(Pyrus arbutifolia)*	3,4,5	Dec. Shrub	no	yes	Moderate, songbirds.	Bank stabilizer. Partial sun.
Red Maple *(Acer rubrum)*	4,5,6	Dec. Tree	yes	yes	High, seeds and browse. Tolerates acidic soil.	Rapid growth.
Red Oak *(Quercus rubra)*	5,6	Dec. Tree	yes	no	High, food and cover.	Gypsy moth target. Prefers well drained, sandy soils.
River Birch *(Betula nigra)*	3,4	Dec. Tree	yes	yes	Low, but good for cavity nesters.	Bank erosion control. Full sun.
Scarlet Oak *(Quercus coccinea)*	3,4	Dec. Tree	no	no	High, food and cover.	Gypsy moth target. Difficult to transplant.
Shadbush, Serviceberry *(Amelanchier canadensis)*	5,6	Dec. Tree	yes	yes	High, nesting, cover and food. Birds and mammals.	Prefers partial shade. Common in forested wetlands and upland woods.
Silky Dogwood *(Cornus amomum)*	5,6	Dec. Shrub	yes	yes	High, songbirds, mammals.	Shade and drought tolerant. Good bank stabilizer.

****Zone 1: Submergent Aquatic Vegetation***
****Zone 2: Shallow Water Bench - 6-12 inches Deep***
****Zone 3: Shoreline Fringe - Regularly Inundated Area***
****Zone 4: Riparian Fringe - Periodically Inundated Area, Wet Soils***
****Zone 5: Floodplain Terrace - Infrequently Inundated, Moist Soils***
****Zone 6: Upland Slopes - Seldom or Never Inundated, Moist To Dry Soils***

Source: Native Plant Pondscaping Guide - Watershed Restoration Sourcebook, Natalie Karouna, MWCOG

Figure E-1b. Native Wetland Plant Guide for Stormwater Management Areas in the Mid-Atlantic -- USA Wetland Plants

Wetland Plants	*Zone	Form	Available	Inundation Tolerance	Wildlife Value	Notes
Arrow arum *(Peltandra virginica)*	2	Emergent	yes	up to 1 ft.	High, berries are eaten by wood ducks.	Full sun to partial shade.
Arrowhead/Duck potato *(Saggitaria latifolia)*	2	Emergent	yes	up to 1 ft.	Moderate, tubers and seeds eaten by ducks.	Aggressive colonizer.
Broomsedge *(Andropogon virginianus)*	2,3	Perimeter	yes	up to 3 in.	High, songbirds and browsers. Winter food and cover.	Tolerant of fluctuating water levels and partial shade.
Cattail *(Typha spp.)*	2,3	Emergent	yes	up to 1 ft.	Low, except as cover.	Aggressive. May eliminate other species. Volunteer. High pollutant treatment.
Coontail *(Ceratophyllum demersum)*	1	Submergent	no	yes	Low, food, good habitat and shelter for fish and invertebrates.	Free floating SAV. Shade tolerant. Rapid growth.
Common Three Square *(Scipus pungens)*	2	Emergent	yes	up to 6 in.	High, seeds, cover, waterfowl, songbirds.	Fast colonizer. Can tolerate periods of dryness. Full sun. High metal removal.
Duckweed *(Lemna sp.)*	1,2	Submergent /Emergent	yes	yes	High, food for waterfowl and fish.	May biomagnify metals beyond concentrations found in water.
Lizard's Tail *(Saururus cernuus)*	2	Emergent	yes	up to 1 ft.	Low, except wood ducks.	Rapid growth. Shade tolerant.
Marsh Hibiscus *(Hibiscus moscheutos)*	2,3	Emergent	yes	up to 3 in.	Low, nectar.	Full sun. Can tolerate periodic dryness.
Pickerelweed *(Pontederia cordata)*	2,3	Emergent	yes	up to 1 ft.	Moderate, ducks, nectar for butterflies.	Full sun to partial shade.
Pond Weed *(Potamogeton pectinatus)*	1	Submergent	yes	yes	Extremely high, waterfowl, marsh and shore-birds.	Removes heavy metals.
Rice Cutgrass *(Leersia oryzoides)*	2,3	Emergent	yes	up to 3 in.	High, food and cover.	Full sun, although tolerant of shade. Shoreline stabilization.
Sedges *(Carex spp.)*	2,3	Emergent	yes	up to 3 in.	High, waterfowl, songbirds.	Many wetland and several upland species.

****Zone 1: Submergent Aquatic Vegetation***
****Zone 2: Shallow Water Bench - 6-12 inches Deep***
****Zone 3: Shoreline Fringe - Regularly Inundated Area***
****Zone 4: Riparian Fringe - Periodically Inundated Area, Wet Soils***
****Zone 5: Floodplain Terrace - Infrequently Inundated, Moist Soils***
****Zone 6: Upland Slopes - Seldom or Never Inundated, Moist To Dry Soils***

Table E-1b (cont.)

Wetland Plants	*Zone	Form	Available	Inundation Tolerance	Wildlife Value	Notes
Sedges *(Carex spp.)*	2,3	Emergent	yes	up to 3 in.	High, waterfowl, songbirds.	Many wetland and several upland species.
Soft-stem Bulrush *(Scipus validus)*	2,3	Emergent	yes	up to 1 ft.	Moderate, good cover and food.	Full sun. Aggressive colonizer. High pollutant removal.
Smartweed (Polygonum spp.)	2	Emergent	yes	up to 1 ft.	High, waterfowl, songbirds, seeds and cover.	Fast colonizer. Avoid weedy aliens such as P. Perfoliatum.
Spatterdock (Nuphar luteum)	2	Emergent	yes	up to 1.5 ft.	Moderate, for food but high for cover.	Fast colonizer. Tolerant of fluctuating water levels.
Switchgrass *(Panicum virgatum)*	2,3,4, 5,6	Perimeter	yes	up to 3 in.	High, seeds, cover. Waterfowl, songbirds.	Tolerates wet/dry conditions.
Sweet Flag *(Acorus calamus)*	2,3	Perimeter	yes	up to 3 in.	Low, tolerant of dry periods.	Tolerates acidic conditions. Not a rapid colonizer.
Waterweed *(Elodea canadensis)*	1	Submergent	yes	yes	Low.	Good water oxygenator. High nutrient, copper, manganese and chromium removal.
Wild Celery *(Valisneria americana)*	1	Submergent	yes	yes	High, food for waterfowl. Habitat for fish and invertebrates.	Tolerant of murkey water and high nutrient loads.
Wild Rice *(Zizania aquatica)*	2	Emergent	yes	up to 1 ft.	High, food. Birds.	Prefers full sun.

****Zone 1:** Submergent Aquatic Vegetation*
****Zone 2:** Shallow Water Bench - 6-12 inches Deep*
****Zone 3:** Shoreline Fringe - Regularly Inundated Area*
****Zone 4:** Riparian Fringe - Periodically Inundated Area, Wet Soils*
****Zone 5:** Floodplain Terrace - Infrequently Inundated, Moist Soils*
****Zone 6:** Upland Slopes - Seldom or Never Inundated, Moist To Dry Soils*

Source: Native Plant Pondscaping Guide - Watershed Restoration Sourcebook, Natalie Karouna, MWCOG

The plant material should conform to the *American Standard for Nursery Stock*, current issue, as published by the American Association of Nurserymen. The botanical (scientific) name of the plant species should be in accordance with the landscape industry's standard nomenclature. All plant material specified should be suited for USDA Plant Hardiness zones 6 or 7 (**Figure E-4**).

For more detail, see the Plant Hardiness Zone map for the Northeastern U.S. at the National Arboretum web site, at http://www.usna.usda.gov/Hardzone/hzm-ne1.html .

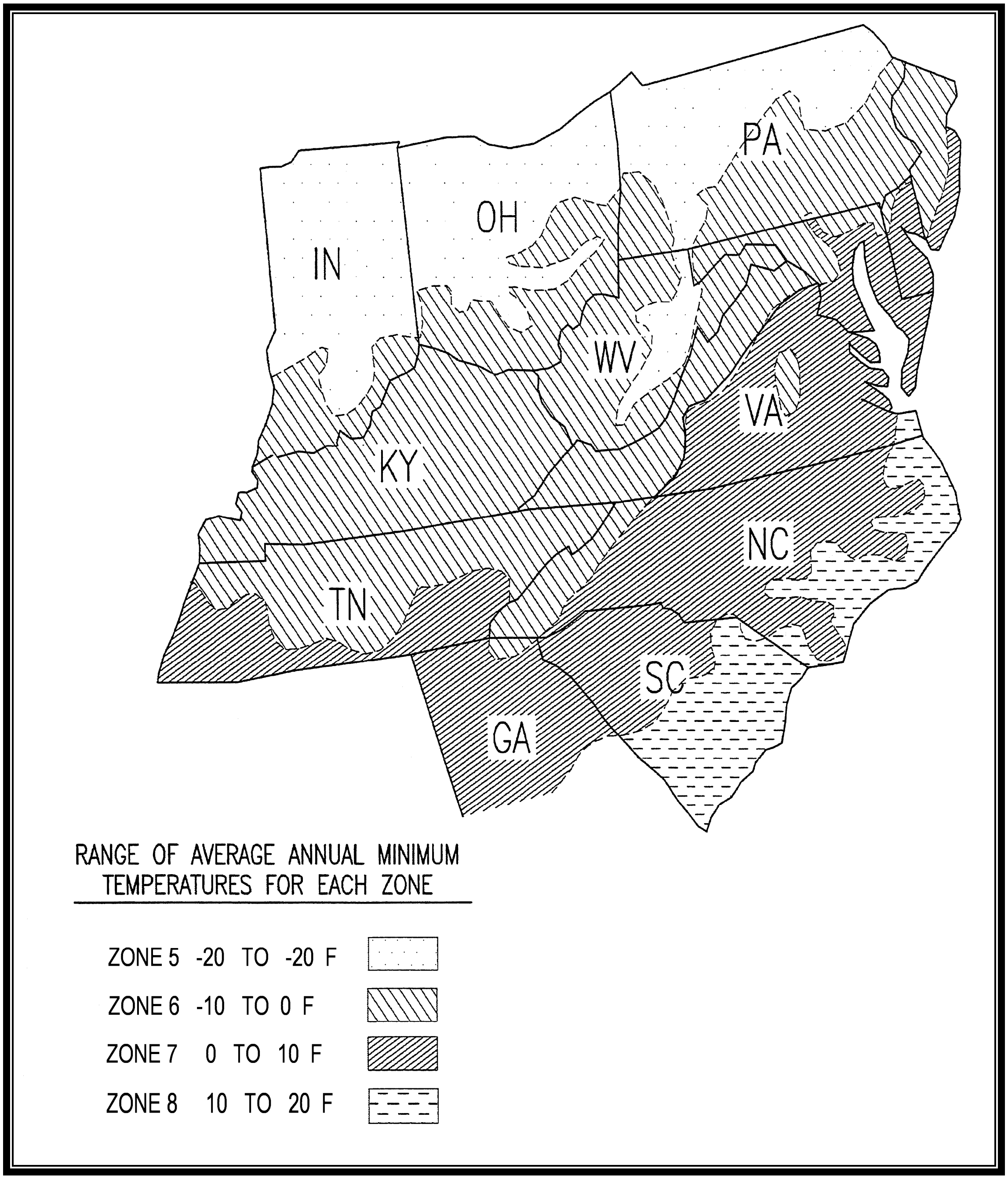


Figure E-4. USDA Plant Hardiness Zones

Newly constructed stormwater BMPs will be fully exposed for several years before the buffer vegetation becomes adequately established. Therefore, plants which require full shade, are susceptible to winter kill, or are prone to wind damage, should be avoided.

Transport and Storage of Plant Material

Specifications may be required for the handling and storage of certain plant materials. Aquatic or emergent plants, for example, require very precise instructions for the contractor. Depending on the time of year and the sequence of construction, it may not be prudent to deliver the plants to the site until the project is ready for landscaping.

Sequence of Construction

The *sequence of construction* describes the site preparation activities such as grading, addition of soil amendments, and any preplanting requirements. It also addresses the installation of erosion and sediment control measures, which should be in place until the entire landscape plan is implemented and the site is stabilized.

Installation of Plant Material

The success of any landscape plan depends on the selection of the proper specifications that are subsequently implemented by the contractor. The specifications should include procedures for installing the plants. They should also provide details for the steps to be taken before and after installation, such as any special instructions for the preparation of the planting pit and fertilization requirements. Any seasonal requirements for installation should also be specified. Typically, containerized or balled and burlapped trees or shrubs should be planted between March 15 - June 30, or between September 15 - November 15.

The placement of trees or shrubs on an embankment is prohibited. The root system of large trees and shrubs can threaten the structural integrity of the embankment and possibly cause its failure.

The side slopes of detention and retention BMPs are usually compacted during the construction process to ensure stability. The density of these compacted soils is often such that plant roots cannot penetrate to an adequate depth, leading to premature mortality or loss of vigor. Therefore, it is advisable to excavate oversized holes around the proposed planting sites and backfill with uncompacted topsoil. In general, planting holes should be 3 times deeper and wider than the diameter of the root ball (B&B stock) and 5 times deeper and wider for container-grown stock (MWCOG, 1992).

Contractor Responsibilities

The contractor should conform to any specifications that directly affect his aspect of the work. He should be aware that there may be penalties for unnecessarily delayed work, minimum success rate of plantings, etc.

For projects involving bio-retention basins or constructed wetlands, it may be advisable to utilize a subcontractor who specializes in aquatic landscaping. The plant specifications, handling, and installation procedures can be unusual compared to traditional landscaping requirements.

SECTION E-8: REGIONAL AND CLIMATE DESIGN VARIATIONS

Plant materials should be selected based on the Plant Hardiness Zone (**Figure E-**3) within which the BMPs are located.

SECTION E-9: TYPICAL GRAPHICAL DETAILS

Not applicable.

SECTION E-10: MATERIAL SPECIFICATIONS

Not applicable. (?)

SECTION E-11: CONSTRUCTION SEQUENCE AND INSPECTION

Not applicable. (?)

SECTION E-12: OPERATION AND MAINTENANCE

A maintenance schedule should be provided in the project plans and/or specifications. This is particularly important for BMPs that have a vegetative component that is integral to the pollutant removal efficiency. The schedule should include guidance regarding methods, frequency, and time of year for landscape maintenance and fertilization.

Specific plant communities may require different levels of maintenance. Upland and floodplain terrace areas, grown as meadows or forests, require very little maintenance, while aquatic or emergent vegetation may need periodic thinning or reinforcement plantings. Note that after the first growing season it should be obvious if reinforcement plantings are needed. If they are, they should be installed at the onset of the second growing season after construction.

Research indicates that for most aquatic plants the uptake of pollutants are stored in the roots, not the stems and leaves (Lepp 1981). Therefore, aquatic plants should not require harvesting before winter plant die-back. There are still many unanswered questions about the long term pollutant storage capacity of plants. It is possible that aquatic and emergent plant maintenance recommendations may be presented in the future.

SECTION E-13: REFERENCES

Arnold, J.A., ed., D.E. Line, S.W. Coffey, and J. Spooner. *Stormwater Management Guidance Manual*. Raleigh, North Carolina: North Carolina Cooperative Extension Service and North Carolina Division of Environmental Management, 1993.

Brady, N.C. *The Nature and Properties of Soils*. New York: MacMillan Publishing Co., 1984.

Chesapeake Bay Local Assistance Department. *Chesapeake Bay Local Assistance Manual*. Richmond, Virginia: 1989.

Chesapeake Bay Local Assistance Department. *Riparian Buffer Modification & Mitigation Guidance Manual,* Richmond, Virginia, *2003*

Chesapeake Bay Program. *Water Quality Functions of Riparian Forest Buffer Systems in the Chesapeake Bay Watershed*. Technology Transfer Report CBP/TRS 134/95. Annapolis, Maryland: 1995.

Dillaha, T.A., R.B. Reneau, S. Mostaghimi, and D. Lee. "Vegetative Filter Strips for Agricultural Nonpoint Source Pollution Control." *Transactions of the American Society of Agricultural Engineers*. Blacksburg, Virginia: 1989.

Fernald, M. L. *Gray's Manual of Botany*. 8th ed. Portland, Oregon: Dioscorides Press, 1950.

Galli, John. *Analysis of Urban BMP Performance and Longevity*. Washington, D. C.: Metropolitan Washington Council of Governments, 1992.

Hampton Roads Planning District Commission. *Vegetative Practices Guide for Nonpoint Source Pollution Management*. Chesapeake, Virginia: 1992.

Hightshoe, G. L. *Native Trees, Shrubs, and Vines for Urban and Rural America*. New York: Van Nostrand Reinhold, 1988.

Karouna, Natalie. *Native Plant Pondscaping Guide*. Anacostia Watershed Restoration Source Book. Washington, D. C.: Metropolitan Washington Council of Governments, 1991.

Metropolitan Washington Council of Governments. *Guidance Report 1: Riparian Buffer Programs, A Guide to Developing and Implementing a Riparian Buffer Program as an Urban Stormwater Best Management Practice*. Washington, District of Columbia: 1993.

Northern Virginia Planning District Commission and Engineers and Surveyors Institute. *Northern Virginia BMP Handbook*. Annandale, Virginia, 1992.

Reed, P. B., Jr. *National List of Species That Occur in Wetlands: Northeast*. St. Petersburg, Florida: United States Fish and Wildlife Service, 1988.

Schlesinger, W. H. and Waring, R. H. *Forest Ecosystems: Concepts and Management*. Orlando, Florida: Academic Press, 1985.

Schueler, T. *Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs*. Washington, D. C.: Metropolitan Washington Council of Governments, 1987.

Schueler, T. "Level Spreader/Filter Strip System Assessed in Virginia" *Watershed Protection Techniques, Vol. 1, No. 1*. Silver Spring, Maryland: Center for Watershed Protection, 1994.

Schueler, T.R., P.A. Kumble, and M.A. Heraty. *A Current Assessment of Urban Best Management Practices*. Washington, D.C.: Metropolitan Washington Council of Governments, 1992.

Schueler, T. "The Architecture of Urban Stream Buffers". *Watershed Protection Techniques, Vol. 1, No. 4*. Silver Spring, Maryland: Center for Watershed Protection, 1995.

Tisdale, S. L. and Nelson, W. L. *Soil Fertility and Fertilizers. 3rd. ed*., New York: MacMillan Publishing Co., Inc., 1975.

Virginia Department of Forestry. *Interim Report to the Chesapeake Bay Executive Council, EC Directive #94-1 Riparian Forest Buffers*. Charlottesville, Virginia: 1995.

Virginia Erosion and Sediment Control Handbook (VESCH). Richmond, Virginia: 1992.

Wong, S.L. and R.H. McCuen. *The Design of Vegetative Buffer Strips for Runoff and Sediment Control*. Tidewater Administration, Maryland Department of Natural Resources, Annapolis, Maryland: 1982.